THE DEFLAGRATION TO DETONATION TRANSITION OF GUN AND SMALL ARMS PROPELLANTS

- A STUDY AND REVIEW -

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ABSTRACT

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Investigations performed in other countries on the deflagration - to - detonation transition (DDT) of gun and small arm propellants have shown that the tendency for a propellant to undergo the transition to detonation, depends upon such factors as composition, (percentage of nitrocellulose, nitroglycerin etc) grain size, web size, number of perforations and other physical and chemical factors. Also, the transition is affected by external factors such as the way in which combustion is initiated in the propellant, the size of the container and the degree of confinement provided by the container or propellant itself.

Some propellants are very unlikely to have a transition to detonation under conditions that exist during manufacturing, handling, storage and transport. Others have been found by investigators in other countries to have so great a tendency for transition to detonation that in almost all cases they should be classified as an explosive - i.e. as hazard division 1.1 (HD 1.1). Still other propellants under some conditions will behave as HD 1.1 and under other conditions they will behave as HD 1.3.

It is not practical to develop special quantity- distance tables for propellants. Instead, what is required is to categorize propellants as to appropriate hazard divisions under the conditions existing during manufacture, handling, storage and transport, and to take the necessary steps to ensure safety. Where it is possible to modify conditions so as to ensure that a propellant behaves as HD 1.3 instead of HD 1.1 this should be done. Quantity-distance requirements for propellants should follow the U.N. quantity-distance tables based on the hazard divisions determined for the propellants as a result of well planned studies and tests. Under no circumstances should a propellant be automatically classed as HD 1.3. However, care should be taken to ensure that it is not unnecessarily classed as HD 1.1.

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THE DEFLAGRATION TO DETONATION TRANSITION OF GUN AND SMALL ARMS PROPELLANTS

- A STUDY AND REVIEW -

1.0 INTRODUCTION

Since the early 1970's at least four accidents have occurred in European countries in which propellants have burned to detonation, that is, have undergone a transition from deflagration to detonation. All of these accidents involved porous small arms propellants. In three cases the accident occurred during or just following the drying stage, possibly initiated by static electricity. The other accident occurred at the loading table during the loading of .22 inch cal. bolt pistol cartridges, possibly due to pinching or friction of propellant in the powder feeder.

In contrast to the accidents in which a fire in a propellant resulted in a transition to detonation there have been other accidents in which very large quantities of propellants, when ignited, continued to burn without explosion or detonation. The main differences between the two types of accidents appear to be that propellants which detonated were of large specific surface (or very small web) and/or were under confinement constraint while those which did not undergo transition to detonation were of a smaller specific surface (or larger web) and were under a low degree of confinement.

This report reviews findings of researchers in other countries who studied the potential of a variety of propellants to detonate under different confinement conditions. Details of work performed in these countries are given in the several appendices to this report. These include information on the tests used in the various studies and the results of those tests.

2.0 THE DETONABILITY OF PROPELLANTS

2.1 General

It is well known that propellants, when suitably initiated by an explosive source, will detonate. As in the case of all explosive materials they will have a critical diameter and an ideal diameter. Some propellants and explosives can undergo low order detonation in addition to high order

detonation. In fact this ability of propellants to detonate in low order has been used in some experimental warhead systems.

Although the ability of propellants to detonate when initiated by an explosive source was well known it was not generally appreciated that propellants, when ignited by a spark, flame or other non-explosive method under suitable conditions, can undergo a transition from combustion to detonation. The porous propellant accidents mentioned above brought wide attention to the deflagration - to - detonation transition (DDT) problem and resulted in extensive studies to develop a better understanding of the phenomenon.

2.2 TNT Equivalence

For purposes of equating blast damage from different explosives it has long been the custom to rate the output of explosives as a percentage of the output of TNT.

In studies of propellant detonation, attempts have been made to apply a similar rating system. While this is acceptable for estimating the propellant output in a large DDT accident it should not be used to reduce quantity-distance values for propellants classed as HD 1.1. If, for example a propellant must be placed in that hazard division but tests have shown that under the test conditions its TNT equivalence is 60%, there is a temptation to reduce the Q-D value. This should not be done, particularly when large quantities are involved. The larger the quantity the greater the possibility for a high TNT equivalence.

3.0 SCREENING TESTS

These tests are used by various countries for two main purposes. First, to determine the potential of different propellants for undergoing transition from deflagration to detonation. Second, for determining the hazard classification of propellants during manufacture and in their storage and transportation containers. The first are small scale tests, the second are tests using larger quantities of propellants.

3.1 Small Scale Screening Tests

Most countries have small-scale tests for preliminary screening of propellants. For the most part these are "go - no go" tests, but some also provide information on critical height for explosion or detonation, and on detonation velocity.

The main types of small-scale screening tests are:

a) Small Diameter Open Tubes

These are steel tubes, closed at the bottom, open at the top. Diameters are between about 40 mm and 80 mm and length from 200 mm to over 1 meter. This type of test is used by Finland and Germany as a "go - no go" test and by France and the Netherlands both as a "go - no go" test and for measurement of detonation velocity and critical height for explosion or detonation. As a simple "go - no go" test, if the tube is fragmented the sample is considered to have exploded or detonated; if the tube remains intact the sample is considered to have only burned.

b) Small Closed Steel Tube

The two countries using this test are France and the United Kingdom. It is primarily a "go - no go" test, however in France it is also used to provide a measure of velocity of detonation and the length of burning before the transition to detonation. In France the tubes are 41 mm I.D. X 200-1200 mm long. In the U.K. the tubes are 76 mm I.D. X 450 mm long. Both have thick walls. In France, detonation is determined by the rupture of the tube, the impression on a lead plate on which the tube rests horizontally and the measured velocity of the reaction front. In the U.K. detonation is considered to have occurred if the tube is broken into 15 or more fragments.

c) Other Small Scale Screening Tests

In Finland, in addition to the small diameter open steel tube test, a card gap, an open channel (trough) and a cap sensitivity test are also used for screening. These can provide some measure of relative sensitivity of propellants to DDT but should be considered more as "go - no go" tests rather than tests which provide reliable quantitative data.

3.2 United Nations Large Scale Screening Tests

All countries use the U.N. Test Series 6 large scale tests to determine the hazard division of propellants in transportation and storage containers. These are, in essence, "go - no go" screening tests where the criterion is either detonation (H.D. 1.1) or no detonation (H.D. 1.3).

3.3 Limitations of Screening Tests

Small scale screening tests, while serving to separate the more sensitive from the least sensitive propellants are generally more conservative than required. The confinement is usually not representative of the degree and type of confinement likely to occur in practice. Also, in some cases the small diameter of the tube may be less than the critical diameter of the propellant being tested.

The United Nations Series 6 tests, particularly Test 6C (Bonfire test), are valid only for the particular conditions of packaging and surrounding confinement. Changes to these have been found to produce results great enough to change a classification from HD 1.3 to HD 1.1 or vice versa.

4.0 THE INFLUENCE OF PHYSICAL AND CHEMICAL CHARACTERISTICS OF PROPELLANTS

Studies discussed in the appendices of this review report have found that most propellants, given suitable conditions, can undergo a transition from deflagration to detonation. The potential of a propellant to detonate depends on its physical and chemical characteristics, that is its "internal" characteristics, and on its "environment" such as the size of its container, its depth in the container and the confinement provided by the container.

This section discusses the influence of physical and chemical characteristics on detonation potential. The next section will consider the influence of environment.

4.1 Influence of Specific Surface and Density

All four of the recent accidents in which propellants burned to detonation involved porous propellants. The probable cause of three of these accidents was static electricity.

Porous propellants are single base propellants in which potassium nitrate has been incorporated into the solvent-wet mix and then dissolved out of the propellant grain. The pores are apparently interconnected.

These propellants have a low density and a high specific surface. Densities may range from about 25 per cent of theoretical maximum density to about 75 per cent. Typically a porous small arms propellant may have a specific surface including pores of about 50 m^2/kg.

Because of its large surface a porous propellant could be expected to have a higher rate of burning than a comparable non-porous propellant. This, in turn, could be expected to result in a higher rate of build up of pressure and a lower critical explosion height (CEH). In one reported series of tests (Appendix E) a porous propellant in a 30 cm I.D., 32 cm O.D. container was found to have a CEH of 40 cm while, under the same conditions, a non-porous propellant had a CEH of 50 cm.

The porous propellant was single-base, single-perforated, short- tube with a web of 0.34 mm, a density of 0.32 g/cm^3 and a specific surface of 48.2 m^2/kg.

The non-porous propellant was very similar to the porous propellant except for its specific surface, and density. It was a single-base, single-perforated, short-tube propellant with a web of 0.33 mm, a density of 0.92 and a specific surface of 5.2 m^2/kg.

One would expect that with such a large difference in the specific surfaces of the two propellants there should be a greater difference in the Critical Explosion Heights (CEH). The answer perhaps lies in the relatively large web of the porous propellant, and thus the limited accessibility of the surfaces of the pores to flame. Also, the porous propellant, by its low density provides less self confinement than the non-porous propellant.

4.2 Influence of Web Size

In non-porous propellants, web size is clearly related to specific surface. Propellants with small webs will have large specific surfaces and for the same form and composition a higher rate of burning. They could therefore be expected to have lower CEH's than propellants with large webs.

Studies performed in France and reported here in Appendix B show a strong dependence of critical explosion height (CEH) on web size. A single-base non-porous propellant with web size 0.2 mm was found to have a CEH of about 0.2 m. The same propellant with a web size of 0.4 mm had a CEH in the same test (200 mm diameter open tube) of 0.85 m. The correspondence between web size and CEH is linear.

In the Netherlands, (Appendix D), it has been determined that finished porous propellants in web size smaller than 0.19 mm (0.0076 in) should always be classified as HD 1.1.

In the Netherlands and the U.S., double base propellants with web smaller than 0.19 mm are classified as HD 1.1. Further information is given in the tables of Appendices D and G.

4.3 Influence of Heat of Combustion

Porosity and web size are, indirectly, measures of surface area available to the flame for burning a propellant. That is, the rate of burning of a propellant depends to a considerable extent on this available surface area. Another factor which will influence the rate of burning is the heat liberated when the propellant burns. A propellant with a high heat of combustion will produce gases at a higher temperature than a propellant with a low heat of combustion. The high temperature accelerates the rate of burning, and if the propellent is confined to any appreciable degree, the pressure in the burning bed. This further accelerates the rate of burning.

Studies performed at SNPE are discussed in Appendix B. These show that the Critical Explosion Height decreases rapidly with increasing heat of combustion.

It should be noted that the heat of combustion of a propellant depends on its composition. A propellant made with high nitrogen nitrocellulose will have a heat of combustion greater than one made with a low nitrogen nitrocellulose. A double base propellant containing nitroglycerin will have a heat of combustion greater than a single base propellant.

4.4 Combined Effects of Density, Web Size and Heat of Combustion

In the above discussion it has been noted that the critical explosion or detonation height of a propellant depends, to a considerable degree, on its density, web size and heat of combustion.

As density decreases the critical height for explosion decreases.

As web size decreases the critical height for explosion decreases.

As the heat of combustion increases the critical height for explosion decreases.

4.4.1 The "R" Factor

In France, Goliger and Lucotte have combined these three parameters to create a factor "R", against which they have plotted the CEH for a large number of propellants including single base porous and non-porous propellants and double base propellants. The factor R is defined as:

$$R = \frac{\text{Heat of Combustion (cal/g)}}{\text{Web (mm) x Bulk Density (kg/m}^3\text{)}}$$

Their graph of R versus CEH is copied as Figure 5 of Appendix B of this review report. It shows an exponential decrease in CEH with increase in R.

The CEH values used in this graph were measured in a 200 mm I.D. open tube. Because of the relatively small tube diameter the curve can not be used to determine from a propellant's "R" value its CEH in other containers. However the CEH values from the 200 mm open tube test are conservative and can be used to provide an estimate of the lower limits of CEH for propellants in larger containers.

4.4.2 Vivacity

Vivacity is the intrinsic rate of burning of a propellant and is usually taken as the rate of change of pressure with pressure.

$$\text{Vivacity A} = \frac{(dP/dt)_{Pa}}{Pa\ Pm}$$

where Pm is the maximum pressure

Pa is the pressure at where dP/dt is measured

This is usually determined by measuring dP/dt at 5 different levels of pressure, Pa, on the rising part of a pressure vs time curve. The measurements are performed in most countries by burning

140 g of the propellant in a standard 700 ml closed vessel (see Appendix D and references therein).

In the Netherlands vivacity is used in conjunction with information on web size, propellant composition and number of perforations to estimate the height of propellant, in standard process and storage containers, above which transition to detonation can be expected to occur (Figures 1 to 6 of Appendix D).

The combination of Vivacity with other physical and chemical properties of a propellant, as is done in the Netherlands, seems to be the most useful method of predicting critical height in process and storage containers.

In Finland, vivacity is used as a test to measure the potential of a propellant to undergo transition to detonation. Propellants with high vivacity have a greater tendency to undergo this transition or undergo it at a lower critical height than propellants with a low vivacity.

5.0 THE INFLUENCE OF PHYSICAL ENVIRONMENT

Environment, in this context, includes the confinement given to a container of propellant by the cross-sectional area of the container, its material and wall thickness, its venting area and by the height of the propellant in the container. It also includes, to a limited degree, the temperature of the propellant.

Although all countries have pointed out that container size, wall thickness and depth of propellant have a strong bearing on whether, in a particular case, a propellant will detonate there is little concrete test data available.

The best data are from papers published by a Swiss researcher, Frauenfelder, discussed in Appendix E of this study review. Frauenfelder's conclusions were:

1) In a mildly ignited propellant charge no transition from deflagration to detonation will occur provided that at least one of the following two conditions is met:

A) the container has a weak point near the point of ignition, such that the weak point will open at a sufficiently low pressure to allow propellant and combustion gases to escape.

B) the height of the bed in an open container is less than the critical height of the bed.

2) The critical height of the bed depends largely on the specific surface of the propellant and to some degree on the propellant temperature.

Point 1 A) above is very important. It means that if self- venting of the container can occur by rupture at a low pressure the contents will not undergo transition to detonation. In the U.S.A., process containers have been designed with a high degree of venting area in order to reduce the potential for detonation (Appendix G). In this regard it should also be pointed out that two massive fires in propellant blending towers in the USA in 1944 did not progress to the detonation stage, possibly because the fires started at the top of the towers, permitting a high degree of venting.

6.0 CONCLUSIONS

1) Most propellants, under suitable conditions, can be made to undergo a deflagration (burning) - to - detonation transition.

2) The potential of propellants to burn to detonation is greatest for propellants having the following physical or chemical characteristics:

a) high specific surface (porosity)

b) small web

c) high energy - eg. double base propellants containing nitroglycerin

d) multi perforated form

e) high heat of combustion

f) high vivacity

g) low density or low bulk density

3) The potential of a propellant to burn to detonation is increased under the following conditions:

a) high degree of confinement provided by the container.

b) violent ignition

c) self confinement provided by a high height of propellant bed

d) restricted venting of propellant gases from the container, allowing rapid build-up of pressure in the container

e) high initial propellant temperature

4) The hazard classification of a propellant should be commensurate with its potential to undergo deflagration to detonation transition and with the height of bed at which this transition occurs under the manufacturing, storage or transport conditions which apply.

5) Under some conditions a propellant should be classed as HD 1.1 and under other conditions as HD 1.3.

6) There is insufficient information on how propellants should be stored in magazines and other storage buildings so as to minimize the potential for build up to detonation of large quantities. Factors to consider include spacing between containers or rows of containers, stacking, and venting.

7.0 RECOMMENDATIONS

1) A catalog should be prepared of all types of propellants made in Canada or imported into this country.

2) All operations involved in the manufacture of propellants in Canada should be reviewed to determine if a potential hazard exists from the point of view of excessive height of propellant bed (for example in driers).

3) All operations involved in the manufacture of propellants in Canada should be reviewed to determine, for each propellant, the hazards from static electricity.

4) All propellant loading operations, particularly of small arms propellants, should be reviewed to ensure that the confinement in loading tubes and hoppers, and the depth of propellant in hoppers does not exceed safe values.

5) Steps should be taken to ensure that allowable propellant depths in containers used for storage and transport are appropriate for the propellant (type, web, etc.) and for the confinement conditions imposed by the container.

6) If necessary, tests should be carried out to determine the critical detonation heights of propellants in the containers used in manufacturing, storage and transport in Canada.

7) A study should be performed to determine safe methods for storage of large quantities of propellants.

8) Quantity-distance tables for propellants should be the existing U.N. Q-D. Table 1 for propellants classified as H.D. 1.1 and Table 3 for propellants classified as H.D. 1.3.

9) The TNT equivalence of a propellant should not be used to modify Q-D Table 1 distance values.

10) The methodology used in the Netherlands for catergorizing propellants for manufacture should be considered for adoption in Canada. This methodology is described in Appendix D and shown diagrammatically in Figures 1 through 5 of that Appendix.

APPENDIX A

FINLAND

STUDIES OF PROPELLANTS - BURNING TO DETONATION

FINLAND

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

As a result of a major accident in a small arms propellant loading plant in 1976 at Lapua, Finland completely revised its Explosives Act and Explosives Regulations (1980). Finland also carried out extensive studies of the sensitivity of propellants and of their potential for burning to detonation.

The tests which were found to be most indicative of a propellant's potential for deflagration-to-detonation transition were:

- Closed vessel vivacity
- Card gap
- Open channel (Trough)
- Cap Sensitivity
- Steel Tube (Open Tube)

Of these:

a) the steel tube test is a means of obtaining a quick "go - no go" indication of transition potential;

b) the closed vessel vivacity test provides a scientifically measured value which, together with web size and composition can be used to provide a reasonably quantitative measure of the transition potential and hence of critical height of propellant for explosion or detonation.

1.0 ACCIDENTS

There has been one instance of explosion or detonation of a propellant in Finland. This was at the Lapua Cartridge Factory on 13 April 1976. The propellant primarily involved was a Nobel CK N04 small arms propellant 62.7% NC, 36.3% NG used for loading 0.22 inch Cal. "bolt pistol" cartridges. A total quantity of about 700 kg of propellants detonated.

The investigation found that the most probable starting point of the detonation was in a packing groove beside the "dosing" cup which measured the propellant into the cartridge. From this loading table position, flame could proceed up the loading tube to the powder loading hopper and, making the transition to detonation, could initiate detonation in nearby boxes and other hoppers. The loading loft contained N310, N340 and N140 single base propellants in addition to the CK NO4 propellant.

2.0 SEALED TUBE REACTION RATE

This test was carried out as part of the Lapua Accident investigation[1,3]. The apparatus was a brass tube 39mm I.D., 42mm O.D. and 1.2 m long. It was completely closed at the lower end. The upper end was closed with a flange that had a central hole 10 mm in diameter through which the propellant, was ignited by an electric squib.

The materials tested were those which were present in loading bays, the powder loft at the time of the accident and also F65/75 black powder.

Results are shown in Table 1. The N310 and N340 are single base porous propellants, N140 is a single base non-porous propellant and Nobel CK NO4 is a double base (63/36 NC/NG) non-porous propellant.

The tube used in this test was of the same material and inside and outside diameters as the powder tube leading from the powder loft hopper to the loading table.

POWDER	REACTION RATE MAXIMUM ATTAINED (m/s)	LENGTH TO ATTAIN DETONATION (cm)	TIME TO ATTAIN DETONATION (ms)	NOMINAL THICKNESS (mm)	WEB (mm)	WEB (inches)
N 310 SB Porous Short Cylinder	3800	12-25	10-20	0.6	0.6	0.024
N 340 SB Porous Single Perforation	3200	12-25	10-20	0.8	0.25	0.010
N 140 SB Non-Porous Single Perforation	500	NO DETONATION		0.7	0.5	0.020
Nobel CK No 4 DB Non-Porous Disc 0.9X0.5mm	3900	12-25	10-20	0.5	0.5	0.020
Black Powder F 65/75	294	NO DETONATION				

SB = single base
DB = double base
The density of N 310 powder was 0.48 g/cm^3 and the density of N 340 powder was 0.56 g/cm^3.

TABLE 1: SEALED TUBE REACTION RATE

3.0 SMALL SCALE STUDIES AND TESTS

Since the Lapua accident, the Kemira Oy company and the Research Centre of the Finnish Defence Forces have studied several test methods to attempt to characterize 32 different single, double and triple based propellants[2]. The test methods were: fallhammer, friction, spark sensitivity, rifle bullet, steel tube, cap sensitivity, card gap, open channel and closed vessel vivacity tests.

Of these the fallhammer, friction, spark sensitivity and rifle bullet tests were found to be unsuitable.

Cap sensitivity and steel tube tests appeared to be suitable as screening tests to indicate the potential of a propellant to burn to detonation. Card gap, open channel (ie trough) and closed vessel vivacity tests were considered to be the best for accurate characterization.

Unfortunately, the results available to us identified the propellants only by type and did not give data on composition, web size or density. However, the correlations noted above are quiet evident. Table 2 is from a paper presentedby A. Maki and A. Kariniemi at the 17th International Annual Conference of ICT, 1986, Karlsruhe[2].

Limited data is available from other sources[1] on some of the propellants (see Table 1).

N 310 is a porous single base, short cylinder propellant of nominal length 0.8 mm and nominal "thickness" 0.6 mm (0.024 inches).

N 340 is a porous single base, tubular propellant of nominal length 1.2 mm and nominal "thickness" 0.8 mm (0.032 inches).

N 140 is a non-porous single base tubular propellant of nominal length 1.25 mm and nominal "thickness" 0.75 mm (0.030 inches).

These three propellants were in the powder loft at Lapua at the time of the explosion. From Table 2 it would appear that N 310 and 340 will be prone to burning to detonation and that N 140 may be borderline safe. This is supported by the test results shown in Table 1.

POWDER TYPE	CLOSED VESSEL VIVACITY (sec^{-1})	CARD GAP (cm)	OPEN CHANNEL (m/sec.)	CAP SENSI-TIVITY	OPEN STEEL TUBE
N312	3,9	0,0	0,29	+	+
N310	3,3	6,3	0,30	+	+
N320	2,7	6,4	0,21	+	+
N340	2,2	6,7	0,20	+	+
N335	2,0	6,4	0,22	+	+
10B27	1,7	8,2	0,16	+	-
3N36	2,8	6,5	0,13	+	+
N330	1,7	6,8	0,22	+	+
N331	1,4	7,2	0,22	+	+
15B59	1,3	8,2	0,14	+	-
N110	1,1	4,7	0,15	-	-
10B33	0,7	3,4	0,20	+	-
N120	0,8	3,7	0,15	-	+
N133	0,7	3,4	0,14	-	-
N140	0,5	3,5	0,15	+	-
15B43	0,7	3,3	0,13	+	-
N130	0,7	3,6	0,10	-	+
N160	0,5	3,0	0,13	-	-
N135	0,6	3,1	0,11	-	-
N165	0,5	3,0	0,11	-	-
N125	0,6	3,8	0,05	+	-
11B75	0,4	2,5	0,13	-	-
2N15	0,4	0,3	0,19	+	-
11B41	0,3	2,3	0,05	-	-
6B8	0,1	2,3	0,04	-	-
9D1	0,04	0,8	0,10	-	-
11B37	0,1	0,0	0,13	-	-
14D91	0,1	0,0	0,12	-	-
13N24	0,1	1,1	0,06	-	-
14D9	0,04	0,2	0,08	-	-
11B60	0,1	0,8	0,04	-	-
25N42	0,2	0,2	0,05	+	-

TABLE 2: THE RESULTS OF VARIOUS TESTS BY KEMIRA OY

The laboratory scale tests most appropriate to propellant detonation studies are:

a) cap sensitivity and open steel tube tests used for screening;

b) card gap, open channel and closed vessel tests used in Finland for characterization.

These are described below from the data of Maki and Kariniemi cited above.

3.1 Cap sensitivity test

The cap sensitivity test is performed as follows. One kg of the propellant to be tested is put into a plastic bag. This bag is hung in free space at a level of one meter above the ground. The charge is initiated with no. 8 electric cap at the centre of the sample. An explosion or detonation is considered to have occurred when no remains of unburnt propellant are found on the ground. If a sample fails to detonate on the first test, two more cap sensitivity tests are carried out.

3.2 Steel tube test (open tube)

The steel tube used in the test is 350 mm long with a welded steel sheet measuring 100 X 100 X 3 mm at the bottom end. The external diameter of the tube is 50 mm and the wall thickness 3 mm. Through the tube is drilled a hole with 5 mm diameter for ignition at a distance of 50 mm from the bottom. Through these holes is put a sparkler stick and the tube is filled with the propellant to be examined. The tube stands on the ground with the open end pointing upwards as it is ignited. The sparkler stick ignition system was chosen due to slow burning rate.

Each propellant is tested three times. The burning always results either in the total fragmentation of the tube or the tube remaining intact.

3.3 Large scale gap test

The gap test gives an indication of the relative sensitivity of the explosive or propellant to a shock wave.

The donor charge used in the tests consists of two pressed tetryl boosters measuring D 49.8 X 25 mm. The density is 1.51 g/cm^3 and the weight 73.5 g. These are initiated by a No. 8 electric cap.

1-10 mm thick PMMA (polymethylmethacrylate) sheets are used as the barrier (gap) medium. The propellant under study is put into a 140 mm long seamless metal tube with external diameter 48.3 mm and internal diameter 37.1 mm. The witness plate is a steel plate measuring 10 X 100 X 100 mm. Between the witness plate and the tube there is an air gap of 1.6 mm. The test equipment is attached to a wooden frame so that the witness plate lies on the frame supported at the edges. The center, where the steel tube stands, is left free.

The barrier (gap) thickness that gives a transmission probability of 50% is determined.

3.4 Open channel test

In the open channel test the burning velocity is measured in an open right angled channel. The total length of the channel is 1.3 meters and the channel width is 15 cm. There are two holes in the channel at a distance of one meter from each other and a height of 15 mm from the bottom of the channel. The detectors of a time interval counter are placed in the holes. The detectors are made of two thin isolated copper wires twisted together.

The propellant is laid along the whole length of the channel as a 2.5 cm thick layer. The propellant is ignited at one end by safety fuse. The start and stop pulses are received by an interval counter.

3.5 Closed vessel test (vivacity)

The closed vessel used in Finland for vivacity measurements has a 200 ml volume while the NATO standard is now 700 ml. The smaller vessel is used at a loading density of 0.1 g/ml while the loading density for the larger vessel is 0.2 g/ml. The propellant charge is ignited with 2 g of black powder and an electric fuze head. Pressure versus time is measured with a quartz gauge and vivacity is determined as the rate of change of pressure with pressure. Vivacity is, essentially, the intrinsic rate of burning of a propellant.

It is clear from Table 2 that the tendency for transition from deflagration to detonation is greatest at the higher values of vivacity.

In Finland, vivacity is used as one of a number of tests to determine the potential of a propellant to undergo transition to detonation. In the Netherlands, the other country which uses this test

for deflagration to detonation studies, vivacity is used, in conjunction with other physical and chemical properties, to estimate critical heights for detonation in process and storage containers.

4.0 LARGE SCALE TESTS

Finland uses the U.N. Test series 6 to assist in determining the hazard divisions for explosives and propellants but also makes use of laboratory tests for propellant classification and particularly for pyrotechnic compositions. We did not find out if any large scale tests other then U.N. Test Series 6 were used to determine an "in process" hazard division for propellant.

5.0 PRECAUTIONS

Quantities of propellant at all stages are kept as small as possible and operations are separated from each other by very conservative safety distances. The two most hazardous operations are propellant loading and propellant drying. Loading operations have been completely changed since the explosion: to minimize the amounts of propellant in loading hoppers and loading tubes; to prevent transmission of flame or detonation in loading tubes; to isolate loading hoppers from each other; and to minimize the amount of propellant in the loading loft. In propellant drying - the quantity of propellant is limited to 400 kg, considered to be a safe quantity for the size of container and height of propellant in it.

Safety distances inside the plant for materials that are determined to be in HD 1.1 are between 2 and 5 times greater than the safety distances proposed in the NATO AC/258 tables.

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1) Jorma Karhulahti, (Inspector of Explosives Finnish Ministry of Defence) "Report of the Explosion Accident at the Lapua Cartridge Factory in Finland, 13th April 1976".

2) A. Maki and A. Kariniemi "Testing and Evaluation of the Handling safety of Propellants" - paper presented at the 17th International Annual Conference of ICT, June 25-27, 1986, Karlsruhe.

3) A. Maki and J Kuortti "Investigation of An Explosion at a Cartridge Loading House". International Exchange of Experience on Industry-Connected Accidents of the Explosives Industries VI Congress - Sevilla 1978.

A PPENDIX B

FRANCE

STUDIES OF PROPELLANTS - BURNING TO DETONATION

FRANCE

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

An accidental ignition of a single-base porous propellant in a propellant drying container at the French National Gunpowder Factory, Pont-de-Buis, in 1975 caused the propellant to burn to detonation and triggered a series of similar detonations at other locations in the plant. A total of about 12 tonnes of propellant detonated, creating damage equivalent to about 7 tonnes of TNT.

Over the next 4 years a comprehensive study was conducted to determine the factors which might cause a propellant to detonate.

Small scale tests, mainly in open tubes of two sizes, 82.5 mm and 200 mm, established that the critical heights for explosion and detonation of propellants depended primarily on web size and heat of combustion for the same bulk density, confinement and surface finish. These latter three factors were also found to have significant effects on critical heights for explosion and detonation.

Large scale tests, in which confinement was considerably less than in the small scale open tube tests, showed that critical heights for explosion and detonation were considerably greater than critical heights found in the small scale tests. A significant number of large scale tests have been performed since 1979 to ensure that heights of propellants in hoppers, drying bins and storage containers will be well below critical explosion heights for all propellants.

Propellant web, composition and vivacity have been found in other countries to have a major influence on the potential of propellants to undergo transition from deflagration to detonation. In France a collective factor "R", incorporating web, heat of combustion and bulk density is used to draw conclusions as to critical explosion height of propellants.

1.0 ACCIDENTS

A major accident occurred at the National Gun-Powder Factory, Pont-de-Buis on 7 August 1975. This factory mainly produces single-base propellants for ammunition for light and medium calibre weapons and for sporting rifles. There were a series of explosions which killed 3 workers and injured 64. Studies estimated that 12 tons of single base powder detonated causing damage equivalent to that from about 7 tons of TNT high explosive. The propellant which initiated the accident was a single base porous powder of web 0.3mm (0.012 inches), density 0.5 g/cm^3. The explosion apparently started in a propellant drying container and spread by means of projected metal particles to other containers. There was a delay of 75 sec between the first explosion and further explosions.

As a result of this accident the French Government embarked on a comprehensive study of the factors which might cause a propellant to explode or detonate. This study was mainly carried out by La Societe National des Poudres et Explosifs at the Centre de Recherches du Bouchet. The principal investigators were Mr. Jean-Paul Lucotte[1,2] and Mr. Jean Quinchon[1].

When the factory was rebuilt larger separation distances were used between buildings and processes were modified. In particular, care was taken to ensure that a propellant in drying containers, storage containers, hoppers and other equipment would be as lightly confined as possible and the heights of propellant in these containers would always be below what trials had shown would cause burning to progress to explosion or detonation.

2.0 TESTS TO STUDY THE TRANSITION BURNING-TO-DETONATION

In France several tests are used to study the deflagration (burning) to detonation phenomena in propellants. Each test yields useful results and has its advantages and disadvantages. Each answers some questions but leaves others unanswered.

2.1 Small Scale Closed Tube Test

This is a test which is used to determine the distance required for burning to progress to detonation when a propellant is ignited in a small diameter tube under heavy lateral and end confinement. It serves several purposes; a) to determine if a propellant under confinement is

likely to burn to detonation; b) to measure the pre-detonation length, ie, the distance, after ignition, required for the transition to detonation; c) to measure the detonation velocity attained. This information is useful, among other things, in the design of loading systems for small arms propellants.

The steel tube is 41 mm ID, 49 mm OD and is closed at both ends by screwed caps. Through one cap is a small hole carrying a continuous velocity measuring probe and through the other is a hole to cary the wires for a small igniting charge. This consists of 10 g of fine propellant powder and a small electrical squib. The usual length of the tube is 300 mm but variations are 200 mm and for propellants with a long pre-detonation length, 1,200 mm.

In the test, as illustrated in Figure 1, the tube lies horizontally on and in close contact with a heavy lead plate. The point of onset of detonation is depicted by the location of the heavy impression on the lead witness plate made by the bursting tube. The velocity of that detonation is measured by the probe.

The disadvantages of this test are:

a) The confinement is not representative of the degree and type of confinement likely to occur in practice.

b) The small diameter of the tube may be less than the critical diameter of the propellant being tested.

3.0 TESTS FOR CRITICAL HEIGHT

Goliger and Lucotte[1,2] have conducted extensive investigations of deflagration to detonation behaviour of propellant powders in vertical tubes open at the top end and ignited at the lower end. Experiments were performed with tube diameters between 50 mm and 1600 mm, but mainly in two diameters, 82.5 mm and 200 mm. For the most part the wall- thickness was such that the calculated static resistance of the tube was less than 400 bars (5800 psi).

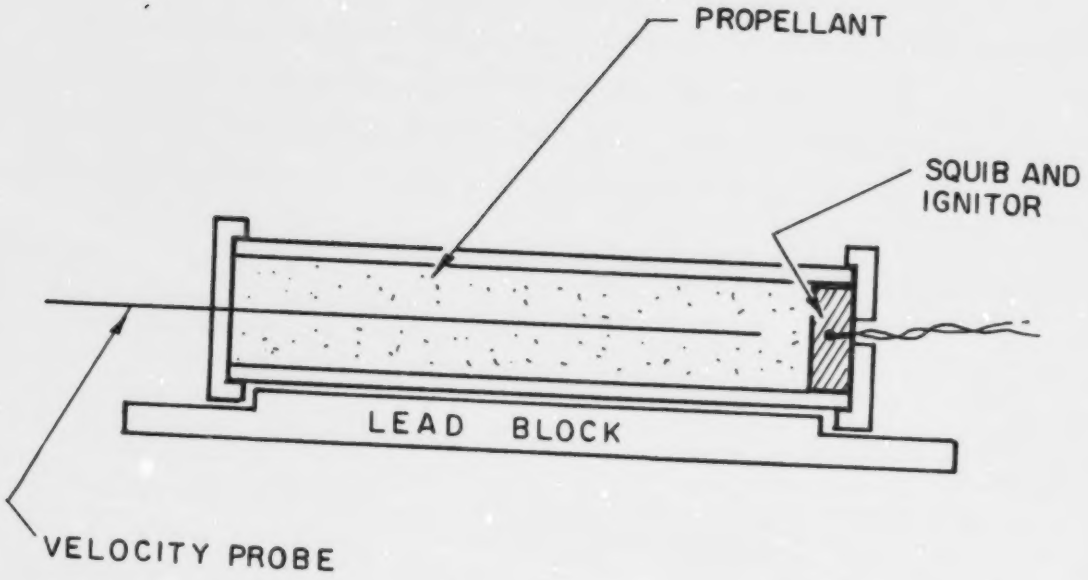

FIGURE 1: SMALL CLOSED TUBE TEST (AFTER GOLIGER & LUCOTTE).

In each series of tests the main parameter which is varied is the height of the bed of propellant powder.

In practice it was found that below a certain height of bed the phenomenon observed was non-violent (ie, combustion). As the height of bed was increased a level was reached where the reaction became violent and could be characterized as an explosion. As the height of bed in the series was increased still more a second level was often reached above which the powder was found to detonate. The first (explosion) level was called "critical explosion height" (CEH) and the second (detonation) level was called "critical detonation height" (CDH).

Ignition in the open tube tests is by a heated wire at the base of the tube.

In developing the tests the parameters studied included[2]:

- type of initiation
- position of the point of initiation
- thickness of the wall of the tube
- diameter of the tube

As noted above, the study resulted in the choice of two diameters of tube as more or less standard, 82.5 mm and 200 mm.

4.0 RESULTS OF OPEN - TUBE TESTS

Lucotte[2] reported in considerable detail at an ICT Conference in 1979 at Karlsruhe on the findings of his studies. These results, taken from his technical paper are summarized below.

4.1 Effect of tube diameter on Critical Explosion Height

This study was performed with a single-base non-porous powder in short stick form. In all cases the tube wall thickness was 1.2 mm. The results show that the Critical Explosion Height increases as the tube diameter is increased. This can also be considered to show that the Critical Explosion Height decreases as the static resistance (confinement) of the tube increases.

The results are shown in Figure 2 (after Lucotte). At the largest diameter studied the sample was considered to have detonated. This result, from a single test, is regarded as tentative.

4.2 Comparison of Results for 82.5 mm and 200 mm Diameter Tube Tests

Results by Lucotte have shown that tests in the 82.5 mm ID, 88.9 mm OD tube are more severe than in the larger diameter tube. The Critical Explosion Heights in the smaller diameter are, on the average, about 2.5 times smaller than the CEH's found in the larger diameter tube tests. This is primarily because the static resistance of the smaller diameter tube is greater than that of the larger tube. Lucotte's results are shown in Table 1.

4.3 Comparison of Critical Explosion Height (CEH) and Critical Detonation Height (CDH)

Studies by Lucotte show that propellants which, in the tube test, have a small CEH also have a relatively small CDH and those with a larger CEH may have a very large CDH. Results of tests in 200 mm ID tubes are shown in Table 2.

4.4 Influence of Web size on Critical Explosion Height

To determine the effect of web size on the Critical Explosion Height, a number of tests were carried out in 200 mm diameter tubes, of non-porous "B" powders. The web of a propellant is the shortest distance between two burning surfaces. In flake propellant the web is the thickness of the flake; in tubular propellant the web is the thickness of the wall. Thus a propellant with a small web will have a larger burning surface area than one with a thicker web and can be expected to burn more rapidly. As might also be expected the Critical Explosion Height is smallest for the smallest webs. As illustrated in Figure 3, after Lucotte.

4.5 Influence of Heat of Combustion on Critical Explosion Height

Propellant powders have different intrinsic energies depending on their constituents. A Ballistite, 60/40 nitrocellulose/nitroglycerin, will liberate more heat on burning than will a single base propellant containing mainly nitrocellulose. Lucotte has conducted tests, in the 200 mm diameter tubes, on propellants of similar web size but with heats of combustion from 700 cal/g to about 1200 cal/g.

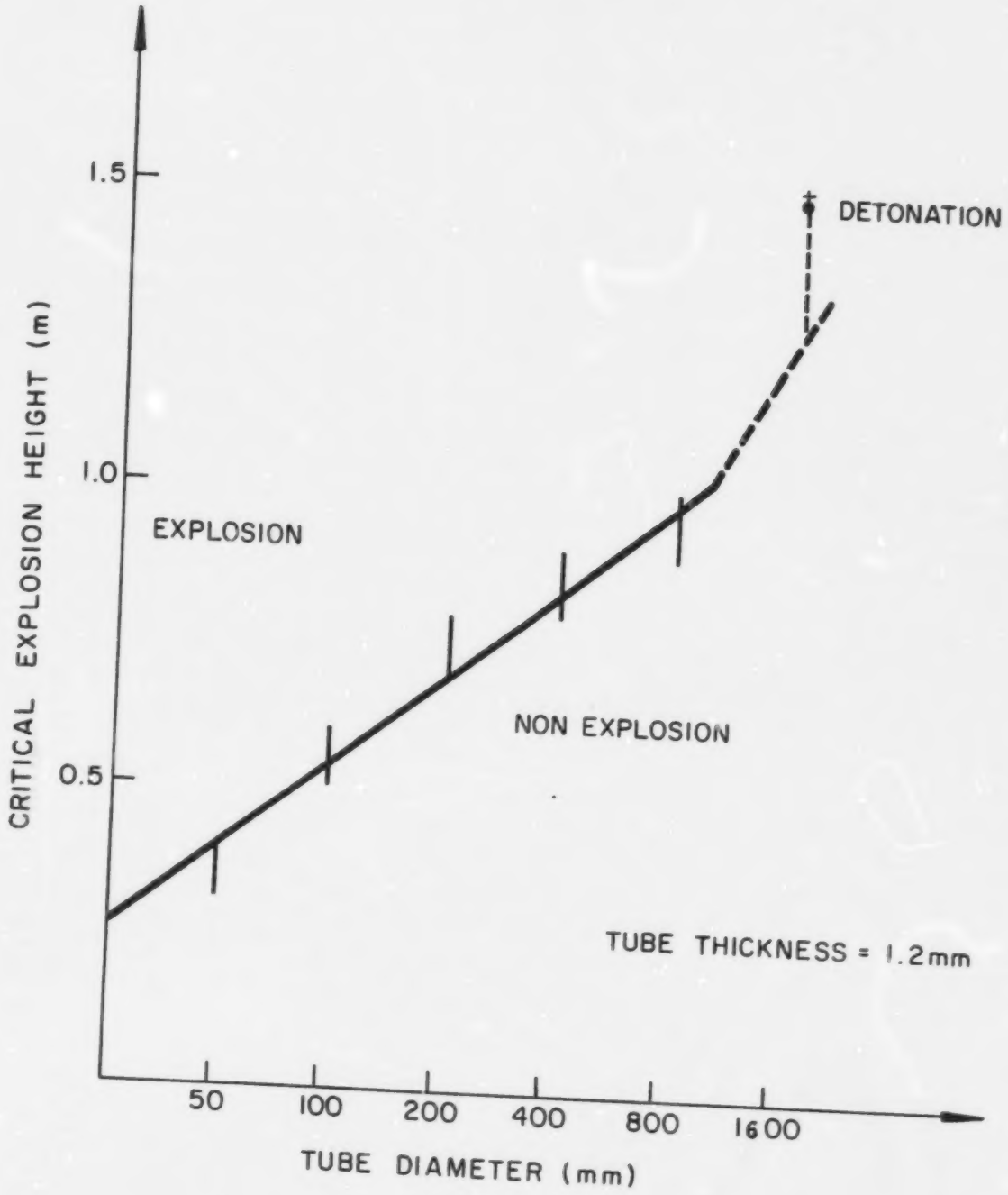

FIGURE 2: CRITICAL EXPLOSION HEIGHT AS A FUNCTION OF DIAMETER POWDER - IN SHORT STICKS.[2]

TEST PROPELLANT	CRITICAL EXPLOSION HEIGHT (m) TUBE 200 mm ID 202.4 OD	TUBE 82.5 mm ID 88.9 mm OD
T	0.4 - 0.5 m	0.25 - 0.35 m
B short stick	0.7 - 0.8	0.4 - 0.5
B tubular	0.9 - 1.0	0.15 - 0.25
Ballistite	0.3 - 0.4	0.10 - 0.15
Ball Powder (coarse)	0.5 - 0.6	0.35 - 0.40
Ball Powder (a) crushed	0.2 - 0.3	0.15 - 0.25
Ball Powder (b) crushed	0.1 - 0.2	< 0.1
Ball Powder (c) crushed	0.4 - 0.5	0.25 - 0.35

NOTE: All powders are single base except ballistite which is about 60/40 NC/NG

TABLE 1: LUCOTTE'S RESULTS.

PROPELLANT	CRITICAL EXPLOSION HEIGHT (m)	CRITICAL DETONATION HEIGHT (m)
B non porous	0.5 - 1.0 m	> 1.8 m
B porous	0.3 - 0.4	0.5 - 0.9
LB	1.0 - 1.1	> 1.8
Ballistite - fine	0.2 - 0.4	0.2 - 0.4
Ball Powder - fine	0.1 - 0.3	0.2 - 0.8
Ball Powder-coarse	0.5 - 0.6	> 1.8

NOTE: L.B. POWDER IS A "COOL BURNING" POWDER i.e. a powder with a low combustion temperature.

TABLE 2: COMPARISON OF CEH AND CDH VALUES, 200 mm TUBE.

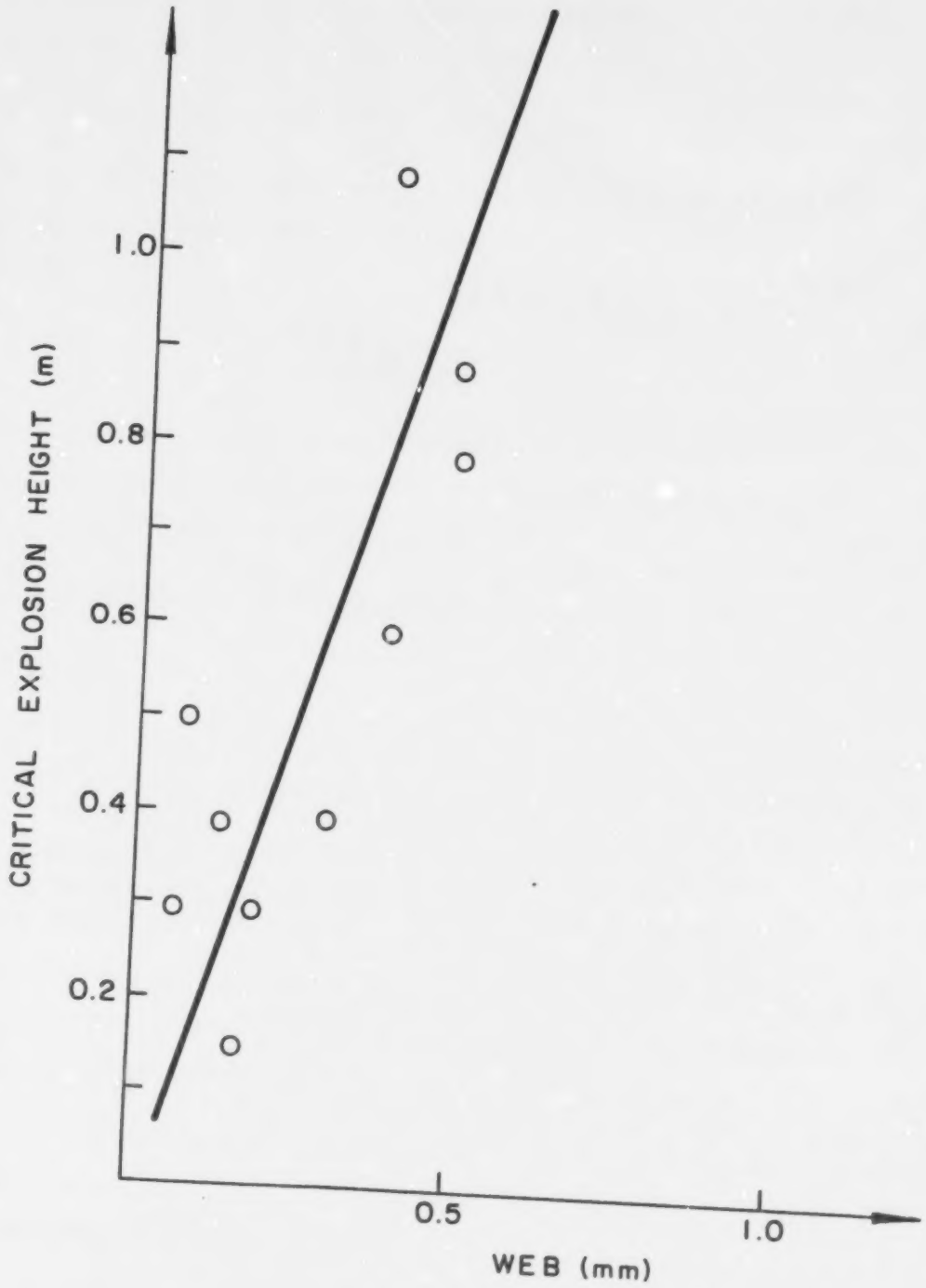

FIGURE 3: CRITICAL EXPLOSION HEIGHT AS A FUNCTION OF WEB (200mm tube) (B type powders). [2]

The results, plotted in Figure 4 show clearly that the Critical Explosion Height decreases with increasing heat of combustion of the propellant.

4.6 The "R Function" - Combined Effect of Web, Heat of Combustion and Bulk Density

Lucotte found that he could relate the Critical Explosion Height of a propellant to a function containing its values of heat of combustion, web thickness and bulk density. This function is defined as:

$$R = \frac{\text{Heat of Combustion (Q) (cal/g)}}{\text{Web (mm) x Bulk Density (kg/m}^3\text{)}}$$

The introduction of a bulk density term permits the self confinement of the propellant to be partially taken into account. Figure 5 relates CEH with R. The function "R" probably would be considered as a pseudo vivacity.

Various propellants were evaluated including three porous propellants.

4.7 Influence of Temperature.

Limited tests in France have shown that there is little difference in Critical Explosion Height between a propellant at about 10°C and the same propellant at 50°C or 60°C.

4.8 Influence of the Condition of the Propellant

4.8.1 Influence of "Finish"

Short grain propellant powders are usually finished by tumbling and graphiting. The tumbling gives a smooth surface for uniform burning. Graphiting coats this surface to minimize the hygroscopicity of the powder.

Tests in 82.5 mm diameter tubes showed that "finished" propellants had little effect on the Critical Explosion Height but a major effect on the Critical Detonation Height, Table 3. This is for a single base non-porous powder.

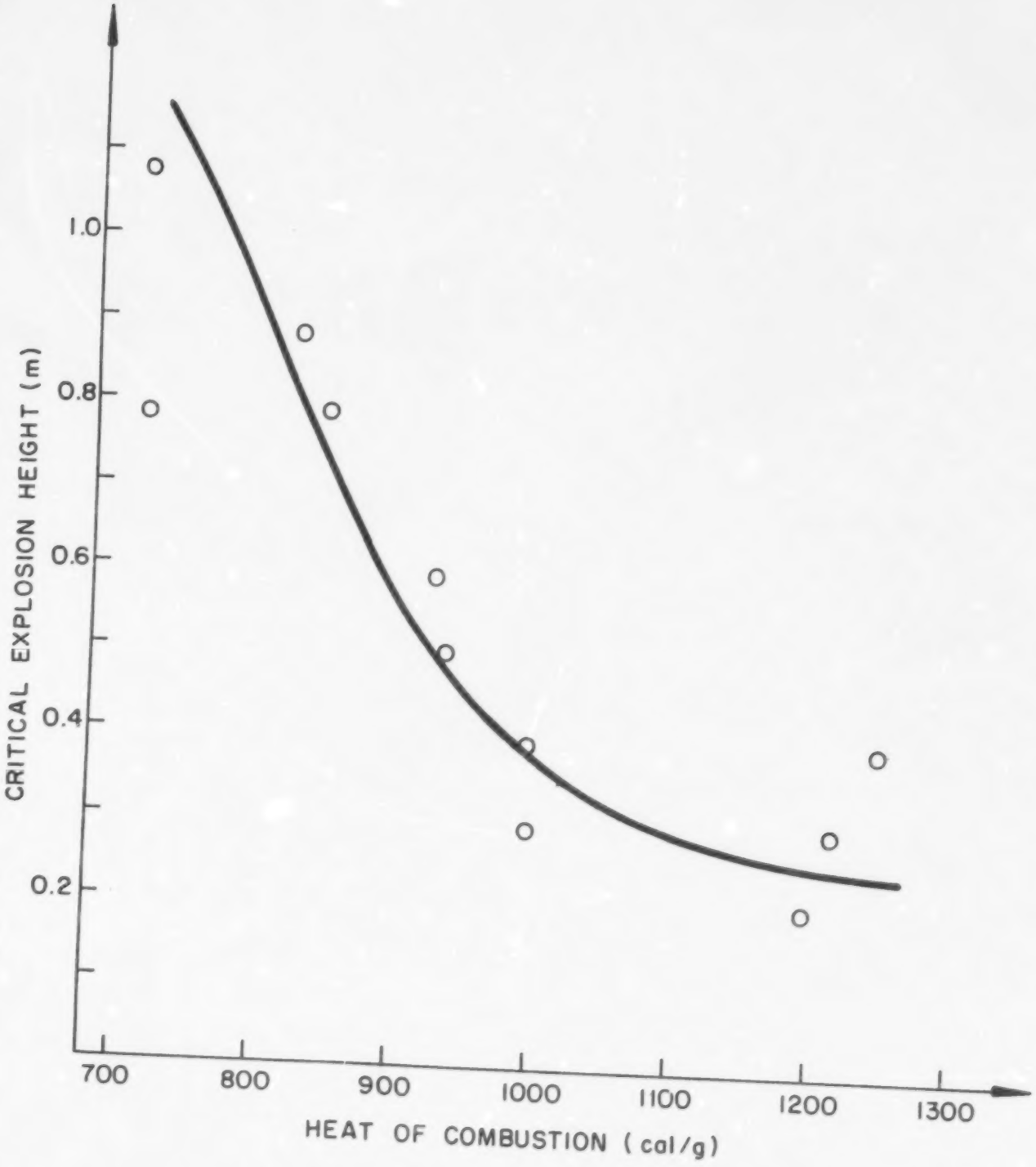

FIGURE 4 : CRITICAL EXPLOSION HEIGHT AS A FUNCTION OF HEAT OF COMBUSTION. (200mm tube). [2]
Note: All Propellants Had Similar Web Sizes.

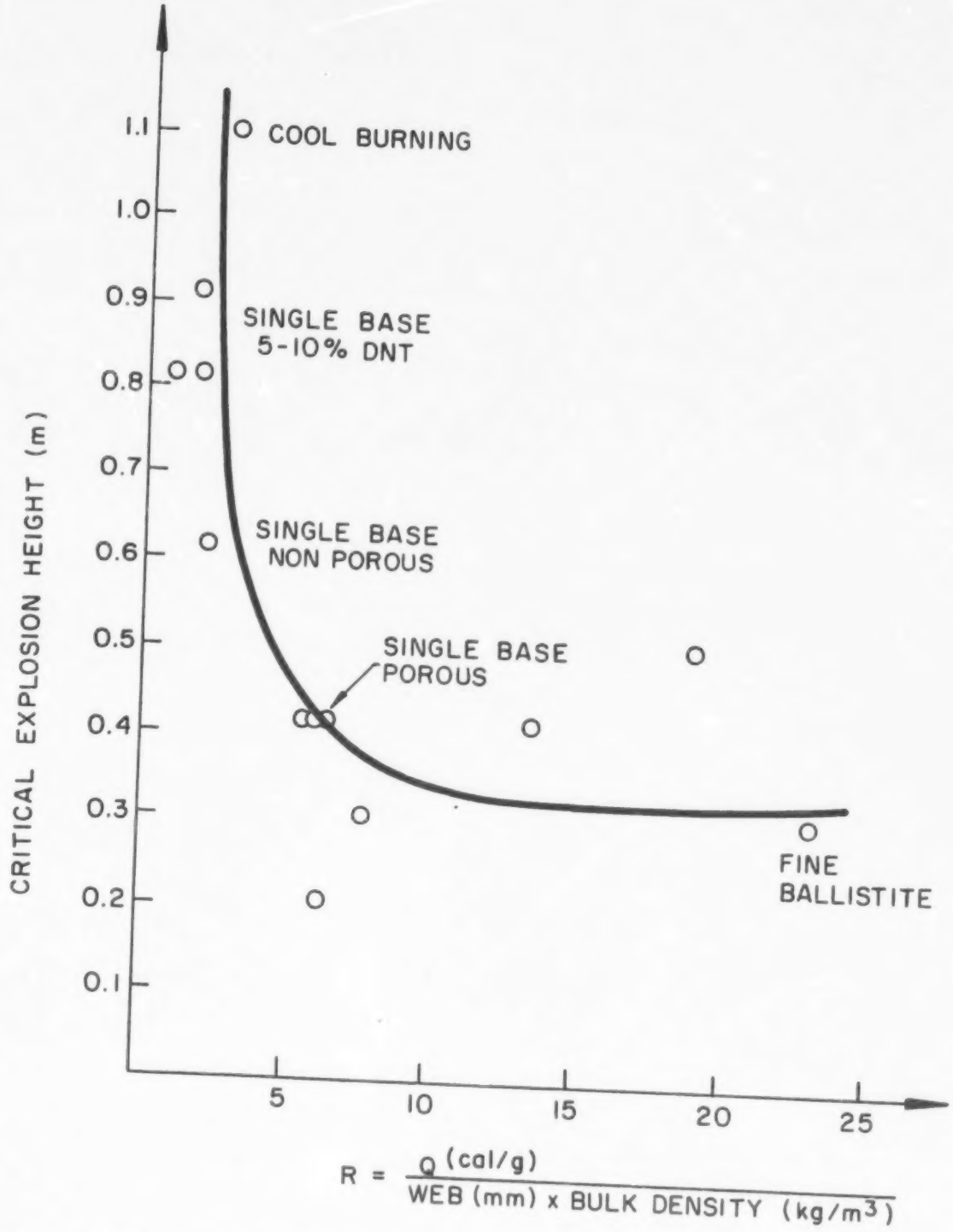

FIGURE 5: CRITICAL EXPLOSION HEIGHT VERSUS R. (200mm tube).[2]

	CRITICAL HEIGHT (m) IN 82.5 TUBE	
	EXPLOSION	DETONATION
Before Finishing and Graphiting	0.15 - 0.25 m	0.25 - 0.50 m
Finished	0.15 - 0.25	> 0.98

TABLE 3: COMPARISON OF CRITICAL HEIGHT FOR FINISHED AND NON- FINISHED PROPELLANT

5.0 LARGE SCALE STUDIES OF CRITICAL HEIGHT

The open tube tests described in previous sections are not usually indicative of most of the conditions pertaining to manufacture, storage and transport of propellants. The quantities of propellant tested in 82.5 mm I.D. open tubes seldom exceed 5 kg and quantities tested in the 200 mm ID open tubes seldom exceed 50 kg.

These tests are very valuable in establishing the influence of various parameters on the CEH and CDH and in comparing the potential hazards of different propellants. However they do not yield values of critical height which can be used with confidence to establish, for example, a safe height of propellant in a drying box or safe dimensions for storage or transport containers. For such purposes larger scale tests in simulated or actual containers, hoppers and drying boxes must still be conducted.

French tests on a large scale with two different Ballistites in casks and in boxes are reproduced in Table 4. The height of powder required to produce an explosion was found to be very much greater than that found in the open tube tests. That is, the open tube tests yield conservative results compared to "field" tests in large containers. Construction and dimensions of containers were not noted in Lucotte's paper. However information from a visit in March 1988 was that these and later tests involved 300-500 kg of powder.

6.0 CONCLUSION

Although the work by Lucotte and by Goliger and Lucotte discussed in this present review was done in the period 1976 to 1979 it remains fully relevant to propellant detonation problems. The closed and open tube tests are the principal small scale tests used in France to study new propellants. Since 1979 France has carried out a considerable number of large scale tests directly applicable to particular manufacturing, storage and transport conditions.

As a result of both the small scale (open tube) tests and large scale tests steps have been taken to reduce hazards in all activities involving propellants. Loading hoppers now have light walls

POWDER	OPEN TUBE TEST 82.5mm CEH (m)	82.5mm CDH (m)	200mm CEH (m)	200mm CDH (m)	LARGE SCALE TESTS IN PACKAGES TYPE OF PACKAGE	NATURE OF IGNITION "ATTACK"	APPROX HEIGHT OF POWDER (m)	RESULT
Ballistite	N.A.		0.2-0.3	0.2-0.3	Wooden Barrel	Exterior Ignition with Fuze	0.55	Combustion
					Box Mle 27 Without Cover	Exterior Fire	0.64	Combustion
					Box Mle 27 With Cover	Exterior Fire	0.64	Combustion
					Box Mle 27 With Cover	Interior Hot Wire	0.64	Explosion
					Box Mle 27 PN With Cover	Interior Hot Wire	0.40	Explosion
Ballistite	0.10-0.15	0.15-0.25	0.3-0.4	0.3-0.4	Wooden Barrel	Exterior Ignition With Fuze	0.55	Combustion

NOTE: DETAILS OF PACKAGE SIZE AND CONSTRUCTION NOT SUPPLIED WEIGHT OF POWDER NOT GIVEN

TABLE 4: COMPARISON OF OPEN TUBE TESTS AND LARGE SCALE TESTS

to reduce confinement. Heights of propellant beds in hoppers, drying boxes and storage and transport containers are now well below the Critical Explosion Height for the particular propellant. Wherever possible smaller quantities of propellant are moved continuously or more frequently instead of moving larger quantities at one time. Large scale field tests have been performed to ensure that the explosion or detonation of propellants in storage locations is not transmitted to adjacent locations.

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APPENDIX C

FEDERAL REPUBLIC OF GERMANY

STUDIES OF PROPELLANTS - BURNING TO DETONATION

FEDERAL REPUBLIC OF GERMANY

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

Germany has had no accidents in which propellants are believed to have burned to detonation.

Although a considerable amount of work is believed to have been conducted on the deflagration to detonation problem we were able to obtain only a small amount of information on the DDT.

One test used extensively in German studies is a small scale open tube test of 50 cm inside diameter, 3 mm wall and 350 mm long. The propellant charge is ignited at the bottom by a small gasless squib. Fragmentation of the tube is taken as indicating explosion or detonation.

In large scale tests, similar to U.N. Test Series 6, German studies have found that the confinement provided by the packaging container can influence whether a propellant behaves as HD 1.1 or HD 1.3.

Quantities of propellants at all stages of manufacture and loading are kept as small as possible. Air drying of propellants is regarded as a major hazard.

1.0 ACCIDENTS

Germany has had no accidents in which propellants are believed to have burned to detonation in process, transport or storage.

One accident occurred in which a propellant is believed to have exploded, but not detonated, in a gun. The pressure was about 15 kbar. The accident was attributed to brittle fracture of the propellant at the firing temperature of -40°C combined with possible improper ignition which resulted in a standing wave in the chamber of the gun.

2.0 SMALL SCALE STUDIES AND TESTS

The one small scale test used by Germany is a steel tube 350 mm long, inside diameter 50 cm, wall thickness 3 mm. The tube is sealed at the bottom, open at the top and is filled with propellant at a loose bulk density. The propellant is ignited at 50 mm from the bottom using a small gasless squib (Pb_3O_4 + Si). Fragmentation of the tube is taken as indicating detonation or explosion. No fragmentation indicates that only burning took place.

This test is very similar to the open steel tube test used in Finland. It differs from the French open tube test.

3.0 LARGE SCALE TESTS U.N. TESTS - TEST SERIES 6

The FRG uses the Series 6 U.N. tests, in some cases with variations, to determine whether an explosive as packaged for transport should be classified as HD 1.1 or HD 1.3.

It has been found that the method of packaging can determine the hazard division. For example, a propellant in a steel shipping drum might test as HD 1.1, but in a fiberboard drum might test as HD 1.3 and in a heavy fibre case again test as HD 1.1.

For this reason they try to store and transport propellants in the type of container that will cause the packaged material to behave as HD 1.3.

4.0 OTHER LARGE SCALE TESTS

The German test agency, BAM, has developed a number of large scale tests in addition to the U.N. Test Series 6. However they were not prepared to divulge these tests at the time of our visit.

5.0 EFFECT OF COMPOSITION, DENSITY, WEB SIZE

BAM regards the information it has on the effects of composition, density and web size of propellants on their hazard division characterization as proprietory and thus declined to discuss this. However they did provide information that:

a) 1/3 of civilian propellants are HD 1.3 2/3 of civilian propellants are HD 1.1

b) almost all military propellants are HD 1.3

c) porous single base powders are usually HD 1.1 in the finished state but before the removal of KNO_3 are usually HD 1.3

6.0 PRECAUTIONS

Quantities of propellants at all stages are kept as small as possible and operations are separated from each other by very conservative safety distances. Air drying of propellants is regarded as a major hazard. It has also been found that close to a propellant or pyrotechnic fire thermal radiation can be a major hazard and can cause injury to personnel or ignition of other materials. Safety glass does not effectively screen people from thermal radiation and should therefore not be used where this is likely to be a hazard.

APPENDIX D

NETHERLANDS

STUDIES OF PROPELLANTS - BURNING TO DETONATION

NETHERLANDS

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

A major accident occurred at the Muiden Chemie B.V. propellant factory near Amsterdam in 1972 during the manufacture of porous propellants. Even before this accident, a special Government Commission had been set up to study the possible risks involved in accidents at this factory. After the 1972 accident a crash program was set up. This crash program, together with the studies of the Commission, resulted in major changes to the factory in terms of process procedures and quantity-distance values for propellants.

Following the crash program, continuing studies by the Company and by the Government laboratory (TNO) have resulted in a methodology for assessing the deflagration-to-detonation potential of propellants, not only in the finished state but also at various stages of manufacture. The main criteria used in estimating this potential are: composition, web size, vivacity. Other factors are also considered, especially solvent content. From these parameters a realistic estimate of critical explosion height can be made. For any significantly new propellant actual large scale tests to firmly establish this height are also performed.

The Netherlands methodology is one which we recommend be adopted in Canada.

1.0 ACCIDENTS

A major accident occurred at the Muiden Chemie Propellant Factory near Amsterdam in 1972 during the manufacture of porous propellants[1]. The most likely cause was considered to be an electrostatic discharge in propellant dust during a drying operation. More than 2 tons of porous single base propellant were involved in the explosion, although not all of this may have detonated or exploded.

A second fatal accident occurred in Muiden Chemie in May 1983. This accident happened when workmen were repacking dried, tubular porous propellant in long igniter stick form from

drying containers into fibre drums. The investigation found that the igniter sticks were strongly charged electrostatically during the drying process. The employees repacking the sticks were also electrostatically charged. It was concluded that a combination of a spark discharge from one of the employees and deposits of dust in a mushroom mixer in the workroom was the cause of the explosion. About 240 kg of propellant exploded; three employees were killed.

2.0 TESTS TO STUDY THE TRANSITION - BURNING TO DETONATION

Following the first accident a "crash" program was initiated to study the deflagration-to-explosion-to-detonation properties of propellants[1]. The tests were "field tests" using large quantities of propellants in containers and boxes closely simulating those used in production, transport and storage of propellants. These tests yielded results which were almost immediately used in propellant operations. However, because of both cost and difficulty in carrying out large scale tests, smaller scale "laboratory" tests were also performed. Both types of tests are described below. Testing was conducted cooperatively by the Government Laboratory (TNO) and by the firm Muiden Chemie.

After the "crash" tests the Company continued with a program to develop more comprehensive information on the deflagration to detonation phenomena.

Following the 1983 accident, TNO again became directly involved in a specific accident study. This was particularly focused on such tests as impact, friction and electrostatic sensitivity. Results of electrostatic sensitivity tests are given later in this review report.

3.0 SMALL SCALE OPEN TUBE TEST

This test is conducted in a steel tube having the following dimensions:

length	- 1.18 m
inside diameter	- 30 and 50 mm
wall thickness	- 10 mm

Its wall thickness and hence, confinement, is considerably greater than the tubes used in similar tests in Finland and Germany. The tube is closed at one end with a screwed cap that has a small hole for the insertion of an igniter which consists of an electric squib plus 2 g of pyrotechnic mixture. A continuous reading wire probe is inserted through the open end along the axis to about 10 cm above the point of ignition at the bottom of the tube. In the test, the tube is filled with propellant and ignited. The probe gives a measure of the distance travelled by the reaction front versus time, from which velocity can be calculated. By replacing the igniter by a small booster charge of plastic explosive and a detonator, the velocity of detonation of the propellant under the same diameter and confinement conditions can be measured. Table 1 gives the results of three typical small scale tests reported by TNO[1]. The three danger classes noted are described below.

4.0 DANGER CLASSES

The Netherlands Government distinguishes a total of 8 danger classes of explosives and ammunition. Of these, propellants form 3 classes.

Danger Class 1

Products falling into this danger class are fire-dangerous. Under the conditions of manufacture of such propellants a transition from burning-to-explosion is not to be expected. The consequences of a fire remain limited and only lead to fire damage in and at the room where the fire took place. Flying fragments are not to be expected at any great distance. If a quantity of this class of material is surrounded by fire, this will not lead to a mass-explosion. This danger class equates to U.N. Hazard Division 1.3.

Danger Class 2

The products falling into this danger class are mass-fire-dangerous. They can cause an explosion, however, without the risk of a detonation. Usually no dangerous flying fragments are formed or pressures are generated which cause structural damage in the surroundings. Burning flying fragments and burning packaging materials can fly about in the case of an explosion. Materials in this danger class are treated in the Netherlands as equivalent to U.N. Hazard Division 1.3 for the determination of safety distances, both interior and exterior.

DANGER CLASS	VELOCITY m/s	
	FLAME IGNITION	BOOSTER INITIATION
1	max 600 m/s	6000 m/s
2	1300 m/s	4000 m/s
5	3200 m/s	4000 m/s

TABLE 1: VELOCITY RESULTS FOR FLAME AND BOOSTER INITIATION FOR A TYPICAL POROUS PROPELLANT .

Danger Class 5

The products falling into this danger class can burn to detonation. This will result in serious structural damage, which is more serious if the quantity of detonating material involved is large. As the quantity of detonating material increases, the effect will be spread further in the surroundings. The pressure- wave and the flame are the most important dangers threatening the surroundings. This danger class equates to U.N. Hazard Division 1.1 but is also a fire hazard. In the Netherlands safety distances for HD 1.1 are more conservative than those recommended in the NATO AC/258 Q-D tables.

5.0 CRITICAL EXPLOSION AND DETONATION HEIGHTS

In addition to its use in classifying a propellant, the open tube test provides information on the height of bed at which transition to explosion or detonation may occur. These are, respectively, called Critical Explosion Height (CEH) and Critical Detonation Height (CDH).

It is obvious that Danger Class 1 materials under the conditions of the open tube test, have a CEH greater than the length of the tube, which is 1.18 m long. In reported results, Danger Class 2 propellants have critical explosion heights less than the length of the tube but do not detonate. Danger class 5 propellants achieve transition to detonation well within the length of the open tube. Critical heights are shown by the point at which the reaction rate (ie., velocity) becomes constant. Critical heights as found in the small scale tests may be different than critical heights found in large scale tests where confinement is different.

6.0 LARGE SCALE STUDIES ("FIELD TESTS")

Three types of large scale tests are used, simulating conditions pertaining to actual practice in manufacture, transport and storage. These are: tests in cylindrical aluminum containers; tests in oblong aluminum containers; tests in fibre-board drums.

These tests were conducted as part of the "crash" program and are still used.

6.1 Tests in Cylindrical Aluminum Containers

These containers have the following dimensions:

inside diameter - 80 cm

wall thickness - 3 mm

height of container - 90 cm

- In the test the propellant is loaded to a height of about 75 cm. (propellant weight 350 kg).

- Ignition is by a squib surrounded by 2 g of a pyrotechnic mixture located at a depth of about 25 cm in the propellant.

- Blast is measured by piezo-electric pressure transducers placed 1 m above ground level and at distances of 25, 50, 75 and 100 m from the container.

Some results of tests are shown in Table 2.

In the test of the single perforated single base propellant compacted by vibration the compaction of the propellant in effect increased the confinement to such a degree that a small quantity of the charge appears to have exploded.

It should be noted that the smallest web for the non-porous propellants was 0.48 mm (0.019 inch). Studies in other countries have shown that non-porous propellants of this web and larger have little tendency to burn to the point of explosion. This and other large scale tests may be varied by increasing or decreasing the height of the propellant bed or changing the point of ignition.

6.2 Tests in Oblong Aluminum Containers

The dimensions of these containers are:

length - 1.25 m

width - 0.66 m

height - 0.71 m

wall thickness - 3.0 mm

TYPE OF PROPELLANT	WEB SIZE mm	inch	BEHAVIOUR	TNT EQUIV.	REMARKS
multiperforated single base	1.3	0.052	burning	NA	
single perforated single base	0.8	0.032	burning	NA	
single perforated single base	0.6	0.024	burning partial explosion	NA 5 - 15 percent	a) loose filled b) compacted
single perforated double base	0.48	0.019	burning	NA	9% NG
porous NC			detonation	20 - 60 percent	

TABLE 2: SOME RESULTS OF TESTS IN CYLINDRICAL ALUMINUM CONTAINERS

Their capacity is 350 kg.

6.3 Tests in Fibre-board Drums

The dimensions of these are:

diameter - 0.36 m

height - 0.60 m

Their capacity is 25 kg.

7.0 ELECTRIC SPARK TESTS

These tests were carried out as a result of the 1983 accident involving centre-core igniter sticks made of porous propellant. The results are summarized in Table 3 with results from a non-porous propellant and a short "T" shaped porous propellant. All propellants were ground to produce powders of different fineness.

8.0 TNT EQUIVALENCE OF PROPELLANTS

When a quantity of propellant is deliberately detonated by means of an explosive booster, it will produce an overpressure shock pulse and an impulse in the same way as any explosive material. As with other explosives, the overpressure and impulse may be greater or less than would be the case with the same quantity of TNT. By comparison of shock or impulse values the propellant can be assigned an equivalence value in terms of percentage of output obtained from TNT.

However, when a propellant is ignited by a flame and burns to the point of detonation, only a portion of the propellant will detonate and generate a shock wave. The TNT equivalence of the propellant in such a case will depend on a number of factors and the same propellant under different conditions may have different TNT equivalence values.

PROPELLANT	PARTICLE SIZE DIAMETER (mm)			SPARK (J)
centre core igniter sticks	0	<	0.5	0.6
	0.5	<	1.0	1.0
non-porous propellant	0	<	0.5	---
	0.5	<	1.0	0.7
porous propellant T 70	0	<	0.06	0.06
	0.06	<	0.1	0.10
	0.1	<	0.2	0.16
	0.2	<	0.5	0.25
	0.5	<	1.0	0.50

For comparison:

Sulphurless mealed gunpowder ignites at 0.45J. PETN and B. HMX have no ignitions at 0.45J (U.K. tests using different apparatus)

TABLE 3: SENSITIVITY OF PROPELLANTS TO SPARK. (MINIMUM SPARK ENERGY FOR IGNITION)

The TNT equivalence of a propellant under a specific condition may be expressed as either a percentage of TNT or as the number of kilograms of the propellant which give the same blast as 1 kg of TNT.

9.0 VIVACITY

The vivacity, A, of a propellant is its rate of change of pressure with pressure.

$$A = \frac{\frac{\Delta p}{\Delta t}}{P \times P_{max}} \quad bar^{-1}\ sec^{-1}$$

The closed vessel used in the Netherlands was not described but is probably the standard NATO type having a volume of 700 mL and a maximum rated pressure of about 248 MPa.

In Canada, this standard is followed. A suitable design is the RARDE Model CV21. Ignition of the propellant powder is usually with a small quantity of black powder and an electrical ignition wire attached to electrodes in the top plug of the closed vessel.

The vivacity of a propellant will depend on such factors as composition, density, web size. The vivacity therefore encompasses a number of the parameters which are known to affect the deflagration-to-detonation transition and can be used to assist in predicting the danger of such an event occurring with a particular propellant.

From limited data available from the Netherlands tests, the Critical Height for Detonation appears to decrease linearly with increasing vivacity.

Methods and equipment for measurement of vivacity are described in References 4 to 7 inclusive.

10.0 DANGER CLASSES AT STAGES IN MANUFACTURE

Netherlands large scale tests have established that as a propellant proceeds through the various stages of manufacture its hazard class may change.

10.1 In the Paste Mixing/Solvent Gelatinizing Process

(a) single based powders will be fire dangerous only, ie. Danger Class 1, by virtue of the phlegmatizing effect of the solvents.

(b) powders containing more than 20% nitroglycerine may fall into Danger Class 2 at this stage.

10.2 In the Solvent Drying Stage

Some powders will change from Danger Class 1 to Danger Class 2 at the point where the remaining solvent is decreased to 12%. Porous powders containing less than 30 weight % of potassium nitrate reach the Danger Class 2 level at this stage. At less than 12% solvent some propellants will be Danger Class 5.

10.3 Pressing Stage

Porous powders, in process, containing more than 30% of potassium nitrate reach Danger Class level 2 at the pressing stage.

At the stage where a powder reaches the Danger Class 2 stage, it is very important to make sure that the charge depth in containers is always less than the Critical Explosion Height. This is particularly important if the powder has the potential of behaving as Danger Class 5. If it is not possible to keep the depth of propellant below the Critical Explosion Height and it has the potential for Danger Class 5, than precautions appropriate to that class should be observed. For Danger Class 5, quantity-distance tables for U.N. Hazard Division 1.1 are appropriate. The TNT equivalence may, in this instance, be taken into account in determining Q-D values.

11.0 PROPELLANT CATEGORIZATION FOR MANUFACTURE

The Netherlands propellant manufacturing company, Muiden Chemie B.V., categorizes propellants into 5 groups for the purpose of establishing danger classes at the factory level. The characteristics and parameters used in identifying the danger class are: composition, number of perforations, vivacity, web size, Critical Detonation Height (CDH).

The propellant groups are:

Group I : Single-perforated, single-base powders with a nitrocellulose percentage ≤ 98% and a web ≥ 0.19 mm.

Group II : Multi-perforated, single-base powders with a nitrocellulose percentage ≤ 98% and web ≥ 0.19 mm.

Group III : Double-base powders with web ≥ 0.19 mm.

Group IV : Triple-base powders with web ≥ 0.19 mm.

Powders which cannot be divided into the above groups form the remaining group:

Group V : Single, double and triple-base powders with web < 0.19 mm and/or a nitrocellulose percentage > 98%.

The roles played by vivacity, web size, composition and form (single or multiple perforated, porous) in determining safe conditions at each stage in the production of propellants are shown in Figures 1 to 5 inclusive. An attempt has been made in Figure 6 to summarize a part of the information contained in Figures 1 to 5. Figure 6 oversimplifies the critical height versus vivacity relationship but at least indicates the essential linearity of that relationship and provides a quick estimate of levels for various propellants. The importance of vivacity and web size in relation to the danger class cannot be overemphasized.

It should be noted that the Netherlands system of hazard classification of propellants was developed from a system used by the U.S. Department of Defense.

11.1 Applicability of the Muiden Chemie B.V. Criteria

The criteria used by Muiden Chemie for designating the danger inherent in factory operations in terms of propellant composition, web, vivacity and other parameters should be directly applicable to many propellant manufacturing, transport and storage situations in Canada because of the similarity in types of propellants. Therefore, consideration should be given to using Figures 1 to 5 in evaluating the safety of Canadian operations and procedures.

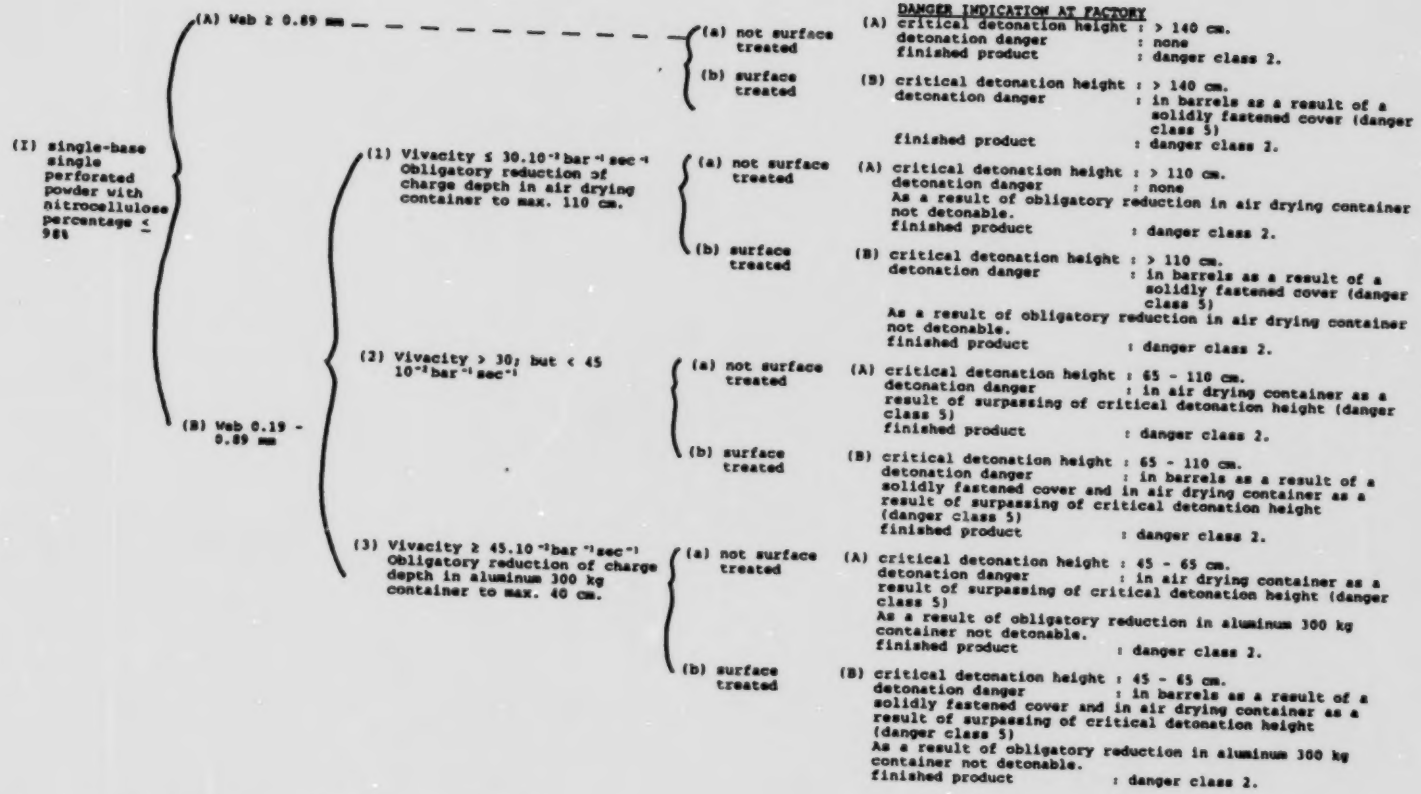

DANGER INDICATION AT FACTORY
(I) single-base single perforated powder with nitrocellulose percentage ≤ 98%
(A) Web ≥ 0.89 mm
(a) not surface treated
(A) critical detonation height : > 140 cm.
detonation danger : none
finished product : danger class 2.
(b) surface treated
(B) critical detonation height : > 140 cm.
detonation danger : in barrels as a result of a solidly fastened cover (danger class 5)
finished product : danger class 2.
(B) Web 0.19 - 0.89 mm
(1) Vivacity ≤ 30.10⁻³ bar⁻¹ sec⁻¹ Obligatory reduction of charge depth in air drying container to max. 110 cm.
(a) not surface treated
(A) critical detonation height : > 110 cm.
detonation danger : none
As a result of obligatory reduction in air drying container not detonable.
finished product : danger class 2.
(b) surface treated
(B) critical detonation height : > 110 cm.
detonation danger : in barrels as a result of a solidly fastened cover (danger class 5)
As a result of obligatory reduction in air drying container not detonable.
finished product : danger class 2.
(2) Vivacity > 30; but < 45 10⁻³ bar⁻¹ sec⁻¹
(a) not surface treated
(A) critical detonation height : 65 - 110 cm.
detonation danger : in air drying container as a result of surpassing of critical detonation height (danger class 5)
finished product : danger class 2.
(b) surface treated
(B) critical detonation height : 65 - 110 cm.
detonation danger : in barrels as a result of a solidly fastened cover and in air drying container as a result of surpassing of critical detonation height (danger class 5)
finished product : danger class 2.
(3) Vivacity ≥ 45.10⁻³ bar⁻¹ sec⁻¹ Obligatory reduction of charge depth in aluminum 300 kg container to max. 40 cm.
(a) not surface treated
(A) critical detonation height : 45 - 65 cm.
detonation danger : in air drying container as a result of surpassing of critical detonation height (danger class 5)
As a result of obligatory reduction in aluminum 300 kg container not detonable.
finished product : danger class 2.
(b) surface treated
(B) critical detonation height : 45 - 65 cm.
detonation danger : in barrels as a result of a solidly fastened cover and in air drying container as a result of surpassing of critical detonation height (danger class 5)
As a result of obligatory reduction in aluminum 300 kg container not detonable.
finished product : danger class 2.

FIGURE 1: GROUP I - SINGLE-BASE, SINGLE PERFORATED POWDER WITH NITROCELLULOSE PERCENTAGE ≤ 98%.

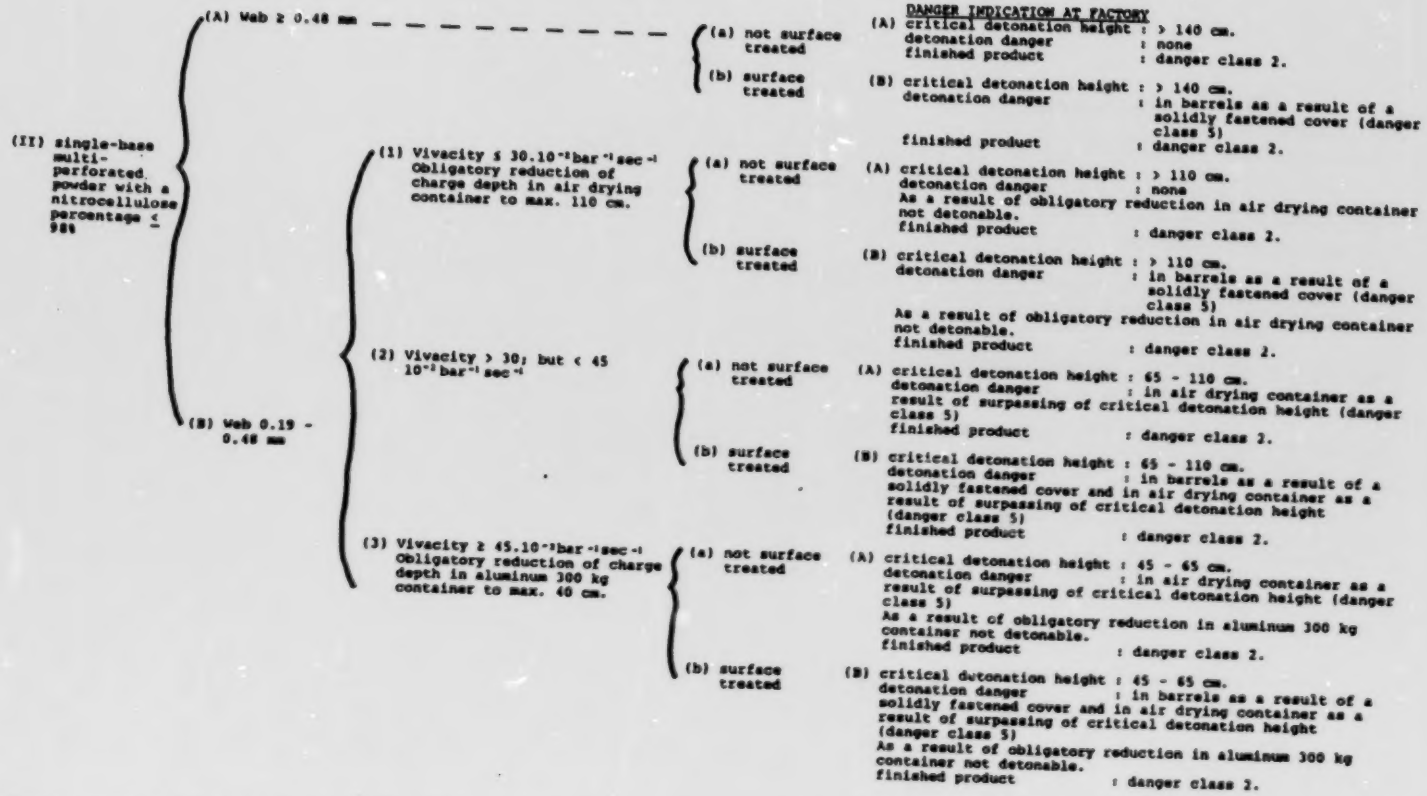
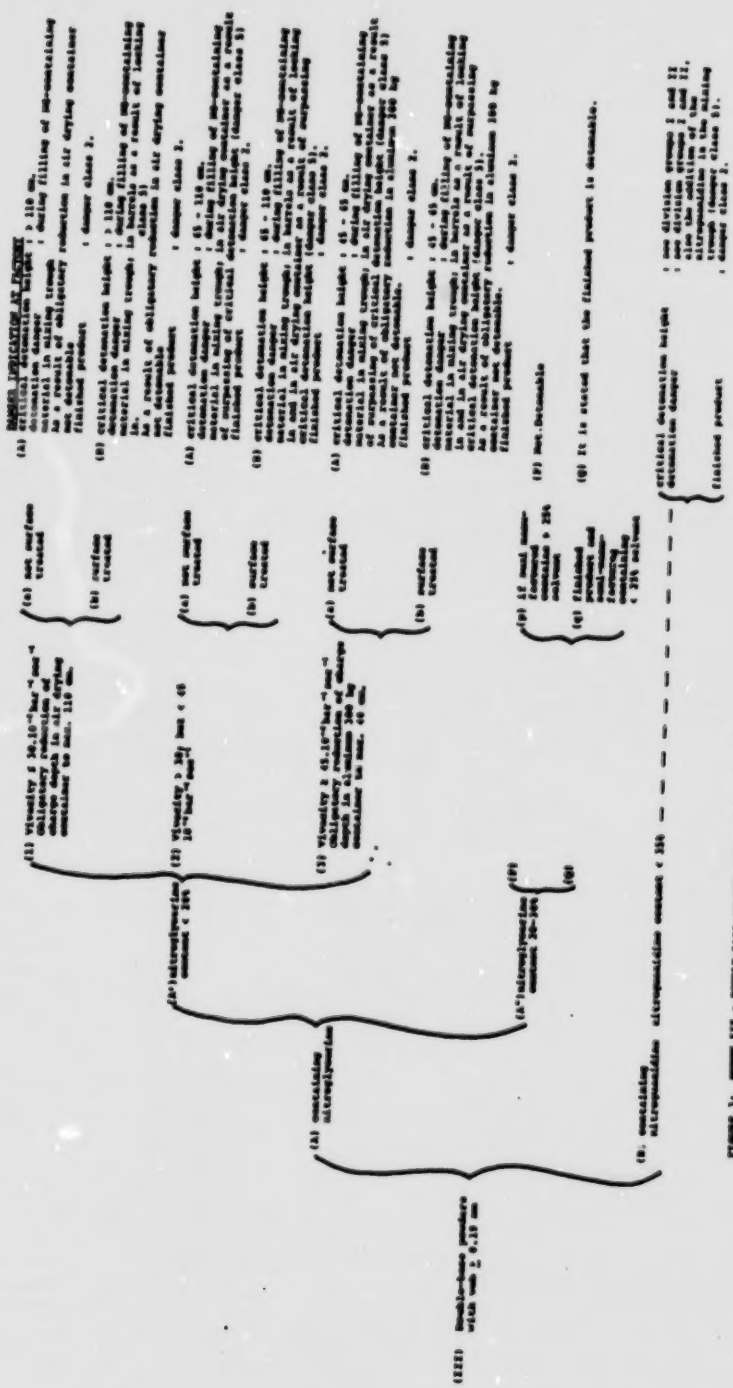
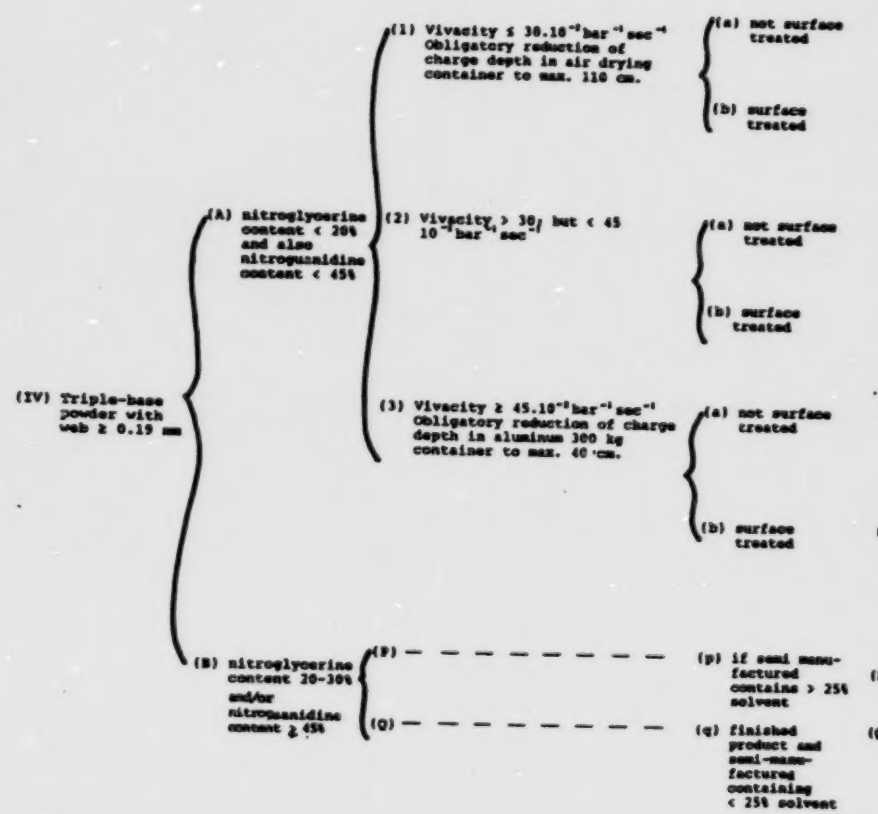

(II) single-base multi-perforated powder with a nitrocellulose percentage ≤ 98%
(A) Web ≥ 0.48 mm
(a) not surface treated
(b) surface treated
DANGER INDICATION AT FACTORY
(A) critical detonation height : > 140 cm.
detonation danger : none
finished product : danger class 2.
(B) critical detonation height : > 140 cm.
detonation danger : in barrels as a result of a solidly fastened cover (danger class 5)
finished product : danger class 2.
(B) Web 0.19 - 0.48 mm
(1) Vivacity ≤ 30.10⁻³bar⁻¹sec⁻¹ Obligatory reduction of charge depth in air drying container to max. 110 cm.
(a) not surface treated
(A) critical detonation height : > 110 cm.
detonation danger : none
As a result of obligatory reduction in air drying container not detonable.
finished product : danger class 2.
(b) surface treated
(B) critical detonation height : > 110 cm.
detonation danger : in barrels as a result of a solidly fastened cover (danger class 5)
As a result of obligatory reduction in air drying container not detonable.
finished product : danger class 2.
(2) Vivacity > 30; but < 45 10⁻³bar⁻¹sec⁻¹
(a) not surface treated
(A) critical detonation height : 65 - 110 cm.
detonation danger : in air drying container as a result of surpassing of critical detonation height (danger class 5)
finished product : danger class 2.
(b) surface treated
(B) critical detonation height : 65 - 110 cm.
detonation danger : in barrels as a result of a solidly fastened cover and in air drying container as a result of surpassing of critical detonation height (danger class 5)
finished product : danger class 2.
(3) Vivacity ≥ 45.10⁻³bar⁻¹sec⁻¹ Obligatory reduction of charge depth in aluminum 300 kg container to max. 40 cm.
(a) not surface treated
(A) critical detonation height : 45 - 65 cm.
detonation danger : in air drying container as a result of surpassing of critical detonation height (danger class 5)
As a result of obligatory reduction in aluminum 300 kg container not detonable.
finished product : danger class 2.
(b) surface treated
(B) critical detonation height : 45 - 65 cm.
detonation danger : in barrels as a result of a solidly fastened cover and in air drying container as a result of surpassing of critical detonation height (danger class 5)
As a result of obligatory reduction in aluminum 300 kg container not detonable.
finished product : danger class 2.

FIGURE 2: GROUP II - SINGLE-BASE, MULTI-PERFORATED POWDER WITH NITROCELLULOSE PERCENTAGE ≤ 98%.





DANGER INDICATION AT FACTORY

(A) critical detonation height : > 110 cm.
detonation danger : during filling of HG-containing material in mixing trough
As a result of obligatory reduction in air drying container not detonable
finished product : danger class 2.

(B) critical detonation height : > 110 cm.
detonation danger : during filling of HG-containing material in mixing trough; in barrels as a result of locking in. class 5)
As a result of obligatory reduction in air drying container not detonable
finished product : danger class 2.

(A) critical detonation height : 65 - 110 cm.
detonation danger : during filling of HG-containing material in mixing trough; in air drying container as a result of surpassing of critical detonation height (danger class 5)
finished product : danger class 2.

(B) critical detonation height : 65 - 110 cm.
detonation danger : during filling of HG-containing material in mixing trough; in barrels as a result of locking in and in air drying container as a result of surpassing critical detonation height (danger class 5).
finished product : danger class 2.

(A) critical detonation height : 45 - 65 cm.
detonation danger : during filling of HG-containing material in mixing trough; in air drying container as a result of surpassing of critical detonation height (danger class 5)
As a result of obligatory reduction in aluminum 300 kg container not detonable.
finished product : danger class 2.

(B) critical detonation height : 45 - 65 cm.
detonation danger : during filling of HG-containing material in mixing trough; in barrels as a result of locking in and in air drying container as a result of surpassing critical detonation height (danger class 5).
As a result of obligatory reduction in aluminum 300 kg container not detonable.
finished product : danger class 2.

(P) Not Detonable

(Q) It is stated that the finished product is detonable.

FIGURE 4: GROUP IV - TRIPLE-BASE POWDER WITH WEB SIZE ≥ 0.19 mm.

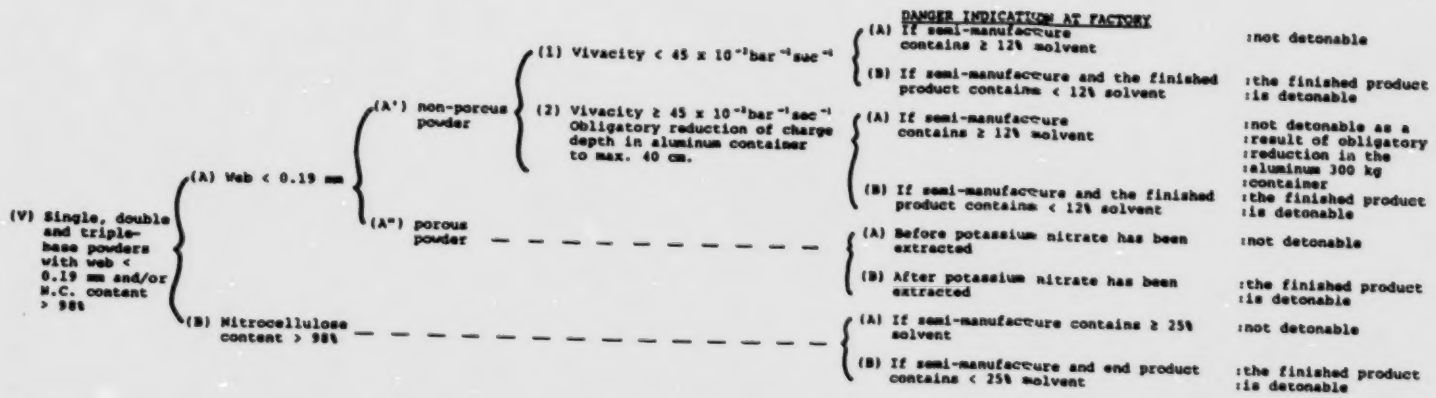

DANGER INDICATION AT FACTORY
(V) Single, double and triple-base powders with web < 0.19 mm and/or N.C. content > 98%
(A) Web < 0.19 mm
(A') non-porous powder
(1) Vivacity < 45 x 10⁻³bar⁻¹sec⁻¹
(A) If semi-manufacture contains ≥ 12% solvent
:not detonable
(B) If semi-manufacture and the finished product contains < 12% solvent
:the finished product :is detonable
(2) Vivacity ≥ 45 x 10⁻³bar⁻¹sec⁻¹ Obligatory reduction of charge depth in aluminum container to max. 40 cm.
(A) If semi-manufacture contains ≥ 12% solvent
:not detonable as a :result of obligatory :reduction in the :aluminum 300 kg :container
(B) If semi-manufacture and the finished product contains < 12% solvent
:the finished product :is detonable
(A") porous powder
(A) Before potassium nitrate has been extracted
:not detonable
(B) After potassium nitrate has been extracted
:the finished product :is detonable
(B) Nitrocellulose content > 98%
(A) If semi-manufacture contains ≥ 25% solvent
:not detonable
(B) If semi-manufacture and end product contains < 25% solvent
:the finished product :is detonable

FIGURE 5: GROUP V - SINGLE, DOUBLE AND TRIPLE-BASE POWDERS WITH WEB SIZE < 0.19 mm AND/OR A NITROCELLULOSE CONTENT > 98%.

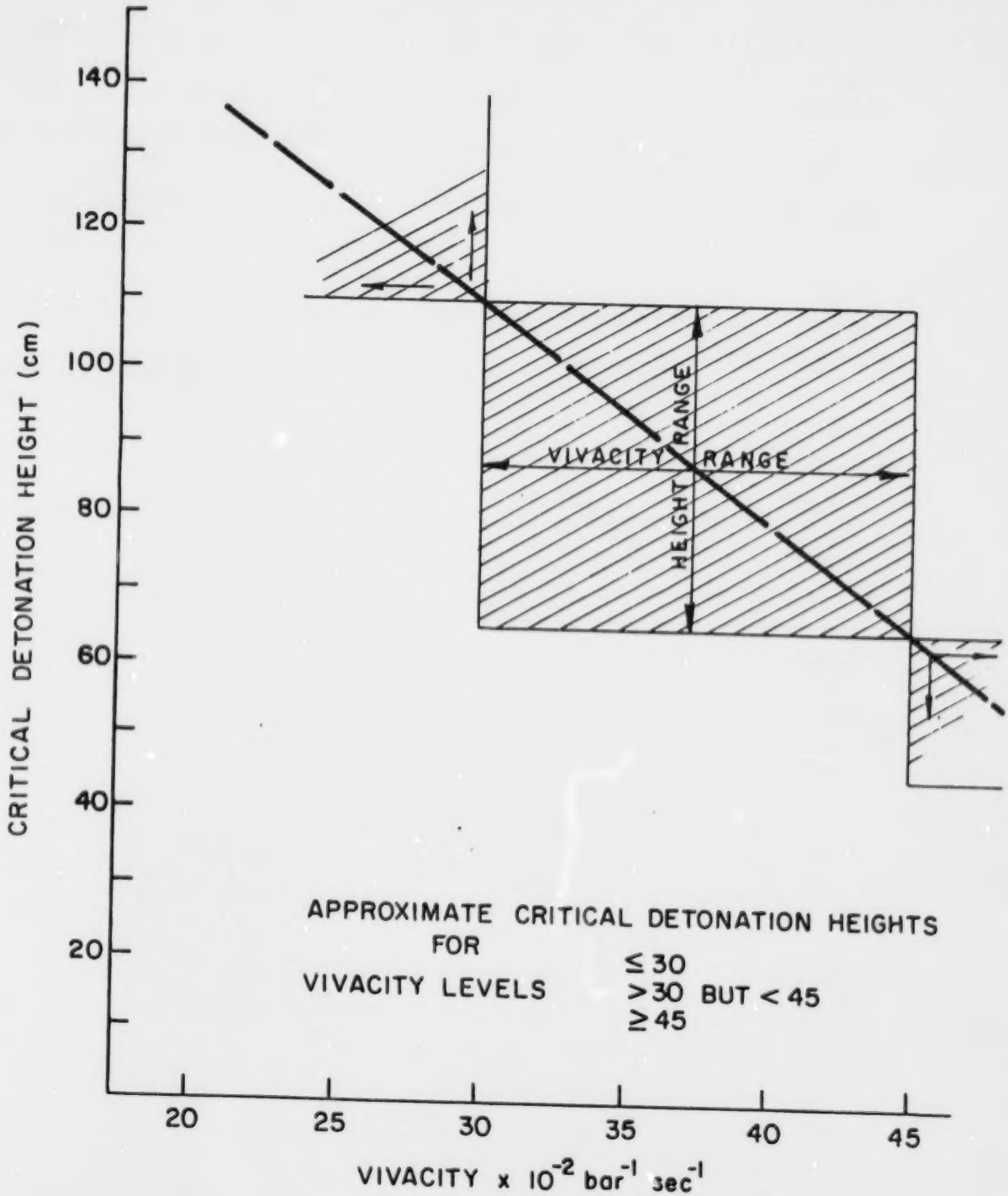


FIGURE 6 : CRITICAL HEIGHT VERSUS VIVACITY

For:		
	Single Base, Single Perf.	Web 0.19 - 0.89
	Single Base, Multi Perf.	Web 0.19 - 0.48
	Double Base	Web ≥ 0.19
	Triple Base	Web ≥ 0.19

REFERENCES

1. Cruysberg, Pasman and Groothuizen: Technical Laboratory, TNO The Netherlands "Propellant Detonation Risk Testing".

2. Muiden Chemie B.V., "The Danger Classes of Propellants", (This appears to be a paper prepared by the Company for private distribution).

3. U.S. Department of Defense, "Contractors Safety Manual for Ammunition and Explosives".

4. NATO STANAG 4115

5. U.S. MIL-STD-286A

6. DND Proof and Experimental Test Establishment Technical Memo 2/68.

7. DREV Memorandum 2708/84.

APPENDIX E

SWITZERLAND

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SWITZERLAND

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

An accident occurred at the Swiss Federal Propellant Plant at Wimmis in December 1978 in a building used for blending and storing propellants. About 100 tonnes of propellant burned very rapidly but did not explode. There were no deaths or injuries. As a result of this the Swiss carried out a major study of their propellant manufacturing and loading operations and, in particular, the potential of three different propellants to burn to detonation when contained in three different types of containers. The containers were of types used for storage and transport of propellants.

The three propellants were:

a) single base, porous

b) flake - similar to Ballistite, web .0076 in. (0.19mm)

c) single base, single perforated, non-porous, web 0.013 in. (0.325 mm)

The large scale tests are important in that they show how critical explosion and critical detonation heights of propellant vary with size and type of container and with propellant web size. However, since only three very different propellants were studied it is not possible to estimate critical explosion or detonation heights for other propellant compositions, web sizes or container sizes and types. Swiss workers have also reported on development and tests of a new building concept for propellant storage.

1.0 INTRODUCTORY NOTE

Switzerland was not one of the countries visited as part of this study. However, we have found that a considerable amount of work has been performed by the Swiss Federal Propellant plant at Wimmis to study the transition from deflagration to detonation of propellants.

The Swiss work is of particular importance because it studies, for three different propellants, the influence of different sizes and types of containers, confinement, critical heights of propellant and the location and type of ignition on the deflagration to detonation behaviour of the propellants. It reports results of large scale types of tests not sufficiently well reported by other countries.

2.0 ACCIDENTS

Swiss studies have been influenced by two accidents. The first of these was not one which occurred in Switzerland but in a Finnish propellant loading plant at Lapua in 1976[1], the design of which was similar to that of a Swiss small arms loading plant. The second accident was one which occurred in the Swiss Federal Propellant Plant at Wimmis in December 1978[2]. In this accident about 100 tons of propellant, in a building used for mixing (blending) and storing of propellants, burned within a few seconds but did not detonate. The building was destroyed but no one was injured.

As a result of the accident in Finland the Swiss conducted a Hazard Analysis study of their own loading plant. The study concluded that it would not be necessary to go to the extent to which the Finns had gone in redesigning the loading plant and processes provided that steps were taken to design their propellant drums and hoppers to prevent propellants burning to detonation in them if accidentally ignited.

To obtain the information needed to design safe drums and hoppers for the propellant loading facility and also to design containers for safe transport and storage, a fairly comprehensive series of large scale tests was performed.

3.0 LARGE SCALE TESTS

The tests reported here are summaries of the tests reported by R. Frauenfelder of the Swiss Federal Propellant Plant (2). His report should be consulted for more detailed results. Three types of propellant were used in three tests. Their properties are given in Table 1. Three basic types of containers, with variations in confinement, were used. These are described in Table 2.

3.1 Tests of Propellants in Container Type 1a

In these tests the three types of propellant were tested at different temperatures and heights of bed to determine a critical height of explosion or detonation. The point of ignition in all tests shown in Table 3 was 5cm above the bottom of the container. Explosion and detonation were determined by the size of the crater, fragmentation of the container and by the noise and flash which occurred.

For the Type 1a container the temperature of the propellant and the height of the propellant bed clearly influence the conditions which will result in a transition from deflagration to detonation. Web size and porosity are relevant to this transition.

3.2 Tests of Propellant Type 3 in Cylindrical Steel Containers Types 1b to 1e.

Containers 1b to 1e all provide less confinement than container 1a because of their lower strength bottom closures. This series of tests was carried out to obtain data on the effect of confinement strength on critical height. Results are shown in Table 4 reproduced from Frauenfelder.[(2)]

Bottom confinement strength of the containers decreases from containers 1b to 1e. Too few tests were done for firm conclusions to be drawn. However, it appears, by comparison of results shown in Table 3 with results in Table 4, that the critical propellant height for containers 1a and 1b are about the same.

There is enough difference in bottom confinement between container 1c and container 1d that detonation occurs in container 1c at a height of bed of 100 cm but does not occur at the same

TYPE	COMPOSITION NC %	NG %	HEAT OF EXPLOSION J/g	THICKNESS OR WALL THICKNESS (web) mm (inches	DENSITY g/cm^3	SPECIFIC SURFACE m^2/kg
Type 1 Porous, single base, single perforated, short tube	96.9	---	3949	0.39 mm (0.0156in)	0.32	48.2 (including pores)
Type 2 Flake	54	42	4884	0.19 mm (0.0076in)	0.71	8.4
Type 3 non porous, single base, single perforated, short tube	96.5	--	3919	0.33 mm (0.0132in)	0.92	5.2

NOTE 1: The Type 3 propellant would appear to be similar to FNH propellants in the 0.012 or .014 web size range. It should be noted that the U.K. considers FNH 014 to be just in hazard division 1.1 .

NOTE 2: The igniters used in all tests were designed to give a purely thermal ignition without the effects of gas shock. Except where specified they were placed 5 cm above the bottom of the container. Each igniter contained 10.4 g of the Type 3 propellant enclosed in wooden cylinders closed at the ends by cardboard discs. Ignition was by an electrically heated wire.

TABLE 1: DESCRIPTION OF PROPELLANTS[2]

CONTAINER	DESCRIPTION
Type 1a	a cylindrical steel container featuring a height of 100 cm, an inside diameter of 30 cm, a wall thickness of 1 cm, without lid, but with a steel base plate of 1 cm welded to the base of the container.
Type 1b	as per (1a) above, the bottom plate being replaced by a steel grate which is fastened to the container with four M 16 screws. A piece of canvas* is placed and pinched between the rim of the container and the grate. The grate mesh measures 30 X 30 mm^2, its ribs 2 X 25 mm^2. The container has four legs welded on its lower part, such that a free space of 115 mm exists between grate and ground.
Type 1c	as per (1b) above, but instead of a grate and canvas, two boards of pine wood, each 12 mm thick being stacked on top of one another.
Type 1d	as per (1c) above, but the base being made of 1 1/2 boards of pine wood.
Type 1e	as per (1c) above, the base consisting of 1 board of pine wood only.
Type 2	rectangular pallet-container, 2 mm corrugated steel plate at the base, 1.5 mm corrugated steel plates at the sides, welded, without lid. Internal dimensions 1197 X 797 X 800 mm^3 high, volume 763 1.
Type 3a	wooden Euro-pallet with wooden side walls made of 30 mm plywood (birch), screwed, without lid. A 5 mm hardboard is nailed upon the pallet floor. Internal dimensions 1140 X 740 X 800 mm^3 high, volume 674 1.
Type 3b	wooden Euro-pallet with wooden side walls made of 19 mm chip board. The pallet floor being covered with a coarse canvas*. Internal dimensions 1162 X 762 X 610 mm^3 high, volume 540 1. This container is suitable for drying out of solvent containing propellants, thanks to its permeable canvas flooring.

NOTE: * The canvas used with containers Type 1b and 3b is twilled linen having 21 threads/cm of cotton yarn Ne 16/2 raw and 17 threads/cm of flax yarn Ne 12/1 raw.

TABLE 2: DESCRIPTION OF CONTAINERS[2].

PROPELLANT TYPE	PROPELLANT TEMP. (°C)	HEIGHT OF BED (cm)	MASS (kg)	CRATER DIAM. (cm)	CRATER DEPTH (cm)	PHENOMONON B = DEFLAGRATION E = EXPLOSION D = DETONATION
1	10	32.0	7.28	---	---	B
	14	35.5	8.08	100	20	E
	12	40.0	9.10	200	40	D
	14	25.5	5.8	---	---	B
	71	24.5	5.58	100	20	E
	64	30.0	6.83	200	30	E/D
2	14	42	21.1	---	---	B
	14	43	21.6	180	30	D
	14	45	22.6	120	20	D
3	12	46.5	30.4	---	---	B
	10	47.5	31.0	---	---	B
	10	50.0	32.6	200	40	D
	10	50.5	33.0	200	40	D
	9	52.0	34	200	50	D
	61	28.0	18.3	---	---	B
	66	30.0	19.6	200	30	D
	59	39.0	25.5	200	40	D
	57	52.5	34.3	200	40	D

TABLE 3: TEST INVOLVING CONTAINER TYPE $1a^2$.

TYPE OF CONTAINER	PROPELLANT TEMP. (°C)	HEIGHT OF BED (cm)	MASS (kg)	HEIGHT OF IGNITER ABOVE FLOOR OF CONTAINER (cm)	CRATER DIAM. (cm)	CRATER DEPTH (cm)	PHENOMENON
1b	11	49.5	32.3	5	100	30	D
1c	11	100.0	65.3	5	200	40	D
	11	100.0	65.3	5	200	40	D
1d	11	100.0	65.3	5	---	---	B*
1e	11	51.5	33.6	5	---	---	B*
	11	60.0	39.2	5	---	---	B*
	11	69.0	45.1	5	---	---	B*
	11	41.0	53.6	5	---	---	B*
	11	90.0	58.8	5	---	---	B*
	11	100.0	65.3	5	---	---	B*
	11	100.0	65.3	5	---	---	B*
	11	100.0	65.3	5	---	---	B*
	11	60.0	39.2	30	---	---	B°
	11	60.0	39.2	30	---	---	B°
	11	60.0	39.2	30	---	---	B°
	11	70.0	45.7	35	150	40	D

B = Deflagration; E = Explosion; D = Detonation

° the wooden floor board was intact after deflagration

* the wooden floor board was fractured and forced out after deflagration.

TABLE 4: RESULT: PROPELLANT TYPE 3^2.

height of bed in container 1d. Similarly propellant in container 1e at a height of bed of 100 cm fails to detonate at a height of ignition of 5 cm above the bottom of the container. However, when the ignition in container 1e is raised to 35 cm above the bottom, detonation occurs with a height of bed of 70cm. Presumably the propellant below the point of ignition offers additional confinement.

3.3 Tests of Large Metal Pallet-Container and Wooden Pallets. (Containers 2, 3a and 3b)

Tests shown in Tables 3 and 4 were conducted in 30 cm diameter cylindrical steel containers with propellant quantities less than 70 kg. In manufacture, storage and transport, propellants are often in much larger containers such as drying boxes, storage boxes, pallet boxes carrying about 500 kg or more. Tests conducted with smaller containers and smaller quantities of propellant might not provide a good indication of the deflagration to detonation properties of the propellants in these larger containers. To investigate this Frauenfelder conducted tests in containers types 2, 3a and 3b. In some tests ignition was at 5 cm from the bottom on the central axes and in other tests it was at the same height but 7 cm from a corner of the rectangular container. Results of Frauenfelder's tests are reproduced as Table 5.

3.4 Conclusions from Large Scale Tests

The Swiss researcher[2] drew the following conclusions from these tests:

a) In a mildly ignited propellant charge no transition from deflagration to detonation will occur provided that at least one of the following two conditions is met:

i) The container has a weak point near the point of ignition, such that the weak point will open at a sufficiently low pressure to allow propellant and combustion gases to escape.

ii) The height of the bed in an open container is less than the critical height of the bed.

b) The critical height of a bed depends largely on the specific surface of the propellant and to some degree on the propellant temperatures.

TYPE OF CONTAINER	PROPELLANT TYPE	TEMP. (°C)	HEIGHT OF BED (cm)	MASS (kg)	POSITION OR IGNITER HEIGHTABOVE FLOOR OF CONTAINER (cm)	UPON VERTICAL AXIS OF SYMMETRY	7 CM DISTANT FROM A CORNER	COMMENT
2	3	14	72	620	5	X		a
		14	74	640	5		X	b
3a	3	14	74	624	5	X		c
		14	74	624	5		X	d
3b	3	11	61	499	5	X		e
		12	61	499	5	X		e
		8	61	499	5	X		e
		4	61	499	5	X		e
		5	61	499	5	X		e
		-5	61	499	5	X		e
		11	61	499	5		X	e

a = the walls of the container became badly distorted but did not rupture.

b = distortion of container negligible.

c = one large side wall broke and was forced out.

d = the container was nearly intact.

e = both large side walls broke and were forced out.

TABLE 5: RESULTS: ALL EXPERIMENTS RESULTED IN DEFLAGRATION[2].

The conclusion (a) (i) above: that a transition to detonation will not occur if a weak point in a container will open at a sufficiently low pressure to allow combustion gases to escape, is important. In essence it means that if self-venting of the container can occur by rupture at a low pressure the contents will not undergo transistion to detonation. In the U.S.A., process containers have been designed with a high degree of venting area in order to reduce the potential for detonation.

4.0 STORAGE CONCEPT

The Swiss have recently reported on tests of a new concept for the storage of granular propellant[4].

This consists of storage buildings that have a number of storage rooms arranged side by side. At one end of these is a large common entrance room, Figure 1. Each room has a light valve type roof consisting of corrugated steel elements pivoted on one side and supported on the other by the crown of the wall. An outline is shown in Figure 2 and details are given in reference (4) including design and test results.

As a result of tests it was concluded that the building is suitable for the storage of propellants that are free of solvents. If solvent containing propellants are to be stored provision must be made to keep the solvent concentration in air below the solvent/air explosion level. The vented roof design is such that pressure within the building remains below 130 mbar for the authorized propellant storage quantity and conditions. Doors are specially designed to be flame proof.

Experiments have shown that in this building the possibilty of a deflagration-to-detonation transition is essentially non-existant provided that the following three conditions are met:

a) That the propellant is stored in "Wooden Europallets" of standardized European design. These have side walls of 19mm thick chip boards, no lids, and pallet floors covered with a standard coarse canvas sheet. Internal dimensions are 1162 x 762 x 610 mm high.

b) The propellant containers must be set up in the storage rooms so as to provide a free space of at least 30 cm by the side of each broad side (1162 mm side) of each container.

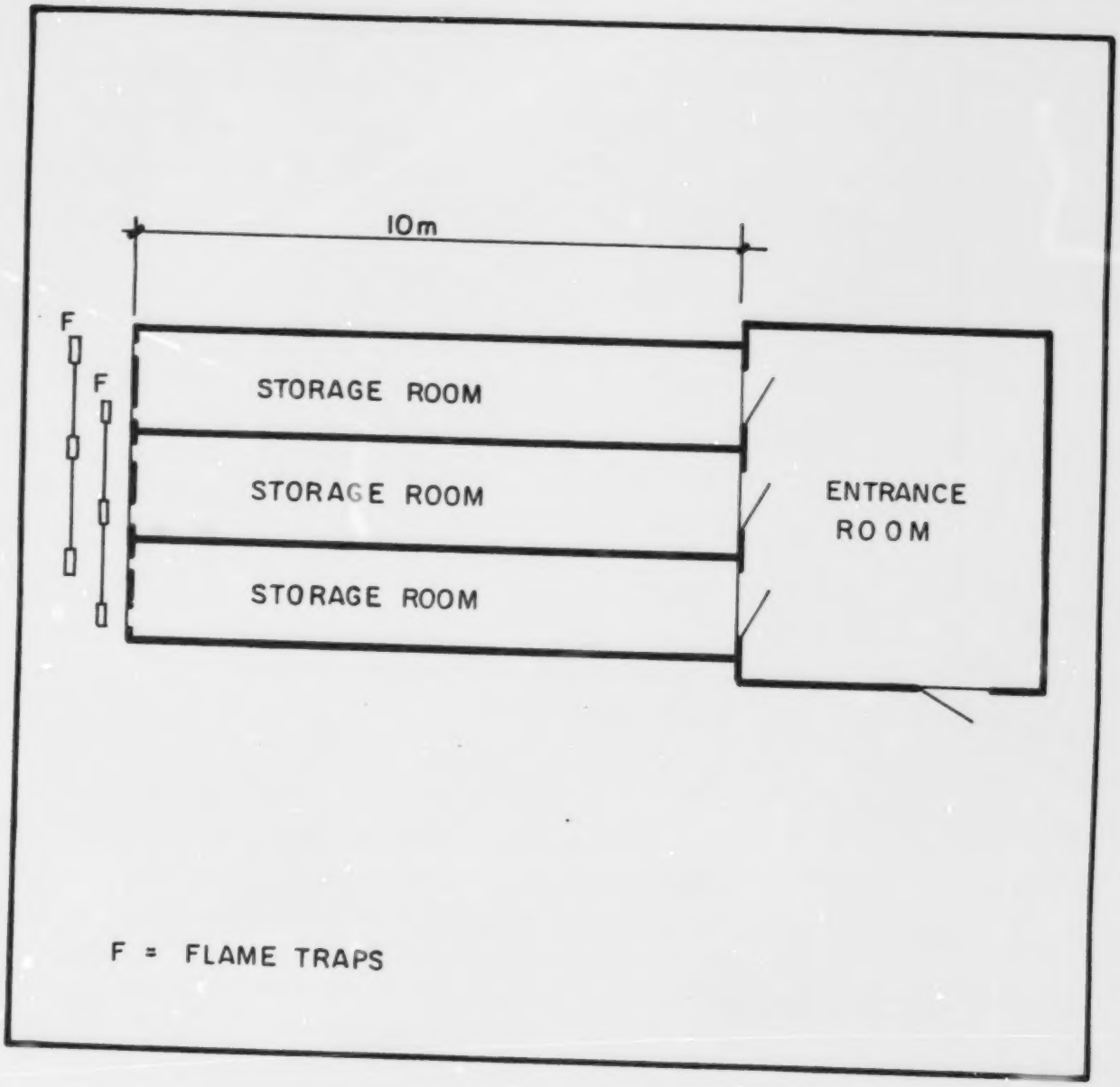
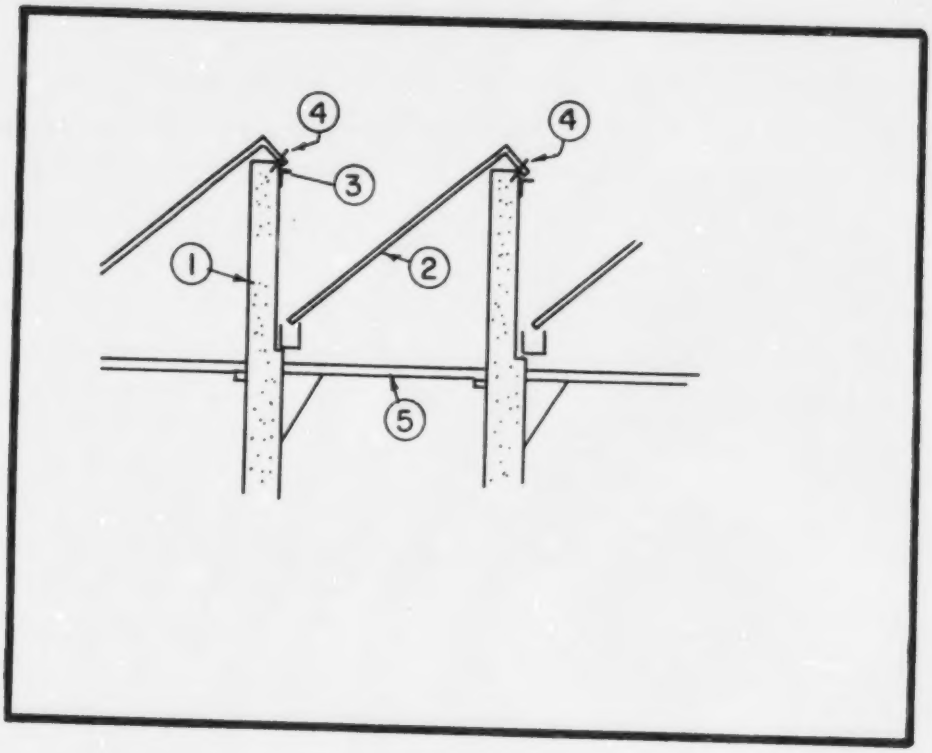


FIGURE 1 : PLAN VIEW OF EXPERIMENTAL BUILDING.



1. REINFORCED CONCRETE WALL
2. CORRUGATED STEEL ROOF ELEMENT
3. ANGULAR STEEL BAR - FOR DEFLECTION OF PROPELLANT GAS FLOW
4. BRASS WIRE TO FASTEN THE CORRUGATED ROOF ELEMENT
5. INSULATION MATTING

FIGURE 2: ROOF DETAIL OF EXPERIMENTAL BUILDING.

This condition allows space for propellant and propellant gases to escape in the case of propellant deflagration within a container causing the side walls to break open.

c) The propellant temperature is less than 30°C and the height of the bed no more than; (i) 60 cm for propellants exhibiting a specific surface of less than 5.5 m^2/kg (web = 0.3 mm or 0.012 inch); (ii) 25 cm for propellants having a specific surface greater than 5.5 m^2/kg (web smaller than 0.3 mm or 0.012 inch)

The heights of bed in (C) above are very small. The intent of this building design is clearly to eliminate the possibility of both detonation of stored propellants and the transmission of combustion from room to room or building to building.

5.0 References

1) Jorma Karhulahti, Inspector of Explosives, Finnish Ministry of defence (no date)

2) R. Frauenfelder. Propellants, Explosives, Pyrotechnics 8, 193 - 198 (1983)

3) Private Communication, B. Thomson, HSE, Buxton, England.

4) R. Frauenfelder. "Testing of a New concept for the Storage of Granular Propellant." Propellants, Explosives, Pyrotchnics 8, 102 - 108 (1983)

APPENDIX F

UNITED KINGDOM

STUDIES OF PROPELLANTS - BURNING TO DETONATION

UNITED KINGDOM

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

The U.K. has had only one possible instance of a propellant burning to detonation. This was in a commercial small arms factory and details were not well known or available.

In general much less work appears to have been done on the problem than in other countries studied. U.K. investigations are primarily of two types:

(a) Laboratory scale tests in a "Large Sealed Vessel" (76 mm I.D X 9.6 mm wall). This is essentially a "go - no go" test depending on the number of fragments into which the vessel is broken.

(b) Large scale tests - based on variations of U.N. Test Series 6.

The U.K. has found that the results of the U.N. tests depend very much on the confinement provided by the container itself and the confinement provided by the method of test - for example in the stack and bonfire tests. Work is now underway using a smaller laboratory scale test.

1.0 LABORATORY SCALE TEST ("LARGE SEALED VESSEL TEST")

This test is U.K. Sensitiveness Collaboration Committee No 3 Test No 10[1]. The test uses about 300 cu. cm of propellant. In the test the boundary between burning and explosion is based on the number of fragments into which the vessel is broken. Less than 15 fragments is considered to indicate burning only. Fifteen or more fragments is considered to indicate explosion in which case they would tentatively classify the propellant as HD 1.1. The vessel is made from a cold-drawn seamless mild steel tube, 76 mm internal diameter and 9.6 mm wall thickness. The tube is closed at both ends and has an effective internal length of 450 mm. The test material is filled to about 25 mm from the top and ignited at the centre by a 3 g SR 371 C igniter. Full

details of the test are given in SCC No 3, including methodology for assessing and reporting the results. HD classification is by comparison of the results from the material under test with those from a standard. The "standard" at present (1988), which is considered in the U.K. to be just in HD 1.3 is Cordite WMT 124/040 (double base propellant 65/30 NC/NG single tube, web 0.042 inches).

A material considered to be just in HD 1.1 is the single base NC powder FNH .014. This is 83% of 13.15N nitrocellulose, 10% DND, 7% stabilizers. However it should be noted that tests (not specified) performed in Australia class FNH 012 as HD 1.3.

1.1 Studies Underway

The U.K. is part way into a sealed vessel study of very fine web advanced experimental gun propellants of the triple base nitramine type. (Porous propellants are too expensive to make in small quantities). The sealed vessel is being "calibrated" against propellants which go HD 1.1 in the U.N. Test Series 6, especially Test 6 (c) Bonfire Test.

2.0 PACKAGED PROPELLANTS - U.N. TEST SERIES 6

The U.K., in general, accepts the U.N. method of classifying packaged explosives by assigning them to a particular hazard division and compatibility group. However U.K. tests have found that the precise packaging method is of fundamental importance in determining this classification. This finding agrees with findings of other countries which have found that the container material, e.g. fibre vs. steel or aluminum, and the height of the propellant in the container, have an important bearing in determining hazard division.

In containers there may be a critical height of propellant, above which the material will burn to detonation. The height of containers should thus be so designed as to preclude propellant heights that could lead to burning to detonation.

U.K. studies have also found that the method of confinement which is used in U.N. Class 1, Series 6 tests can itself be a significant factor in determining the behaviour of the propellant in the tests. For example, it was found that a particular propellant packed in cylindrical tubes exhibited HD 1.1 behaviour in the Series 6 tests when confined by sandbags but when

confinement was by other cylindrical tubes filled with sand the behaviour was as for HD 1.3. The conclusion was that in this and similar cases small variations in the extent of confinement had a significant effect on the behaviour of the propellant in the tests and hence on the hazard division to which it should be assigned.

3.0 PLANS

The U.K. plans to conduct a study aimed at determining conditions which will prevent burning to explosion or detonation under storage conditions. This study, a responsibility of the Explosives Storage and Transport Committee, (ESTC), has not yet started.

4.0 CHANGES TO QUANTITY - DISTANCE TABLES

Initially any changes that will be made will try to reclassify some propellants from HD 1.3 to HD 1.1. A TNT equivalence factor may be used to modify the value of Q.

5.0 TNT EQUIVALENCE IN BURNING TO DETONATION

In U.N. Test 6c the propellant may be somewhat confined, thus it is not easy to get a measure of peak overpressure or impulse if the material burns to detonation. Therefore RARDE relies on crater size to measure TNT equivalance.

6.0 FLEXIBILITY CONSIDERATIONS

As a result of large scale U.N. test Series 6 tests the U.K. has concluded that there may be instances in which a propellant which is classified as HD 1.1 may be safely stored with suitable packaging and confinement conditions, as if it were HD 1.3, thus allowing the storage of larger quantities of the propellant in a particular location.

7.0 GENERAL CONCLUSIONS

It is too early to draw any comprehensive conclusions from U.K. work and studies to date. However the following general conclusions can be drawn:

i) There are situations in which propellants will burn to explosion or detonation.

ii) The large sealed vessel test appears to be a useful tool to study the burning to detonation of propellants. However final classification will probably have to depend on larger scale tests.

iii) There are none of the common propellants which the U.K. would reclassify except small arms propellants in small web size - mainly single base propellants.

iv) The major problem is likely to be in packaging and storage. Under some of these conditions a propellant which tested as HD 1.3 might perform as HD 1.1, ie, might explode or detonate.

REFERENCES

1) United Kingdom Sensitiveness Collaboration Committee Test Manual SSC No 3, Test 10. February 1977.

APPENDIX G

UNITED STATES OF AMERICA

STUDIES OF PROPELLANTS - BURNING TO DETONATION

UNITED STATES OF AMERICA

STUDIES OF PROPELLANTS - BURNING TO DETONATION

SUMMARY

U.S. data has been found to be particularly important to understanding the deflagration - to - detonation transition of propellants.

U.S. criteria for identifying the potential of a propellant to undergo this transition are based on propellant composition (primarily percentage of nitrocellulose and nitroglycerine) web size, and perforation and can be applied to virtually any single or double base gun or small arms propellant for initial categorization of hazard division.

These criteria have been adopted by the Netherlands and further modified to include porous propellants and propellants under process-containing solvents.

U.S. accidents in blending towers and tests of vented and unvented containers in full size and sub-scale size have demonstrated the importance of venting to reduce the tendency of a sensitive propellant to undergo a deflagration - to - detonation transition.

1.0 ACCIDENTS

Accidents in which propellants have burned to detonation have probably occurred in the U.S.A. However, in the time available for this study we did not discover any reports on these.

Important information on two massive fires in blending towers was furnished by Mr. L. Saulnier of the EMR Explosives Branch. In spite of the very large quantities of propellants involved there was no transition to detonation in either case.

Both accidents took place in 1944.

1.1 Alabama Ordnance Works Fire

This fire occurred in a combined blending tower and pack shed. The top bin of the tower was charged with 26,400 pounds of FNH 0.0195 single base powder for 40 mm ammunition. there were also 98,250 pounds of the same granulation in the lower bin and loading hoppers. A total of 147,650 pounds was destroyed. The blending tower was completely destroyed but there was little damage to the pack shed because of a fire wall which separated it from the tower. There were 3 fatalities and 12 major injuries, all from burns. There was no indication of any part of the powder having detonated.

The cause of this fire was not determined. The percentage of dust in the batch was found to be well within acceptable limits and dust conditions throughout the building were said to have been normal before the fire. The point of ignition was not determined but was generally considered to be at the top of the tower. The following possible causes of ignition of powder or dust on the top floor were postulated as:

1) Dropping a powder buggy into the top bin.

2) Rolling a powder buggy wheel over a powder grain causing it to slide and ignite by friction.

3) Ignition of powder dust along the curb, caused by friction when the powder buggy is manoeuvered into dumping position.

4) Static electricity causing ignition of powder dust in the buggy during the dumping of the charge into the top bin.

5) Striking some metallic part of the buggy against the steel guard rails around the charging part or other metal parts of the building or, striking the metal parts of two buggies together.

Although this accident did not result in a transition to detonation a description of the accident and its possible causes have been included here for the following reasons:

a) It indicates that a propellant of this composition, form and web (single base, single perforated with web 0.0195 inches) probably does not readily undergo transition to

detonation, particularly if ignited from the top. If ignition had been at the bottom of the tower the self confinement of the propellant bed might have caused the transition to detonation to take place.

b) It may indicate that the large degree of venting in the tower minimized confinement.

1.2 Louisville Fire

The second blending tower fire was on 13 August 1944 at a propellant plant near Louisville Kentucky and involved about 28,000 pounds of M_3M_1 single base single perforated powder for the 105 mm gun. This was distributed as follows: - about 10,000 pounds in the upper bin; 3000 pounds in buggies on the elevator; the remainder (about 15,000 pounds) in the lower bin or in buggies under the bin.

The cause of the second fire was also not determined. Static electricity was considered to be an unlikely cause since the ambient relative humidity at the time of the accident was 75%. There is always evidence of the presence of a static change on this type of dry, unglazed single perforated powder.

The assumed cause was that the fire was started by impact or friction on powder grains or some foreign object. There were two points at which powder was apparently being moved. One buggy at least, was in some stage of the dumping operation on the top floor. Three buggies on the first floor after the fire showed strong indications of being loaded or in the process of filling. It was therefore concluded that the fire may have started on either the first or on the top floor.

The web of this propellant was not given. However since it is a single perforated cannon powder for 105 mm guns its web is likely to be about 0.015 inch. Propellants of this type and web are not likely to undergo transition to detonation in the absence of a reasonable degree of confinement, particularly if ignited from the top.

2.0 DEFLAGRATION TO DETONATION STUDIES OF GUN AND SMALL ARMS PROPELLANTS

2.1 Open Tube Tests (Hercules/Picatinny)

The critical explosion height for U.S. M1 SP propellant versus diameter was studied by Hercules Inc[1]. The propellant is single- base, single-perforated with a 0.013 inch web.

All tests were with Schedule 40 black seamless steel pipe open at the top and closed at the bottom with a standard pipe cap or other pipe fitting. Nominal diameters ranged from 1 inch to 18 inches. Wall thickness increased with diameter. The propellant was ignited at the bottom by a 12-gram bag igniter (50/50 mixture of FFFG black powder and 2056 casting powder). The bulk loading density of the propellant was about 0.6 g/cm^3. Pipe damage alone was used as the criterion for explosion. An "explosion" was based on rupture or a fragmented pipe and a "no explosion" was based on no damage to the pipe. It was not possible to differentiate explosion from detonation.

Results are shown in Table 1 and Figure 1[1]. The explosion height increases with diameter in a fairly linear relationship.

2.2 Open Tube Test - Naval Surface Weapons Centre

Richard R. Bernecker of the U.S. Naval Surface Weapons Centre[2] has reported on studies of commercial double base ball powders from two manufacturers as part of a broader study of the deflagration-to-detonation transition process for high-energy propellants. The parameters were: composition; particle size; shape; and to some extent, confinement. Confining tubes in most trials were steel 25.4 mm (1 inch) inside diameter, 76.0 mm outside diameter. In two test series the high confinement steel tubes were replaced by lexan low confinement tubes of the same dimensions. Results are shown in Table 2.

3.0 U.S. HAZARD CLASSIFICATION OF PROPELLANTS

The U.S. has established hazard classifications for propellants based on their potential for transition from burning-to-detonation[3,4]. This potential depends on web size, composition and

NOMINAL PIPE SIZE (inches)	INSIDE DIAMETER (inches)	WALL THICKNESS (inches)	CRITICAL HEIGHT TO EXPLOSION (inches)
1	1.05	0.13	7
2	2.07	0.15	12
4	4.03	0.24	13
6	6.06	0.28	16
8	7.98	0.32	22
18	16.88	0.56	32

All pipe - Schedule 40 black seamless steel.

TABLE 1: FLAME-INITIATED EXPLOSION CHARACTERISTICS OF M1 SP PROPELLANT. (Single-Base, Single Perforated, 0.013 Inch Web)

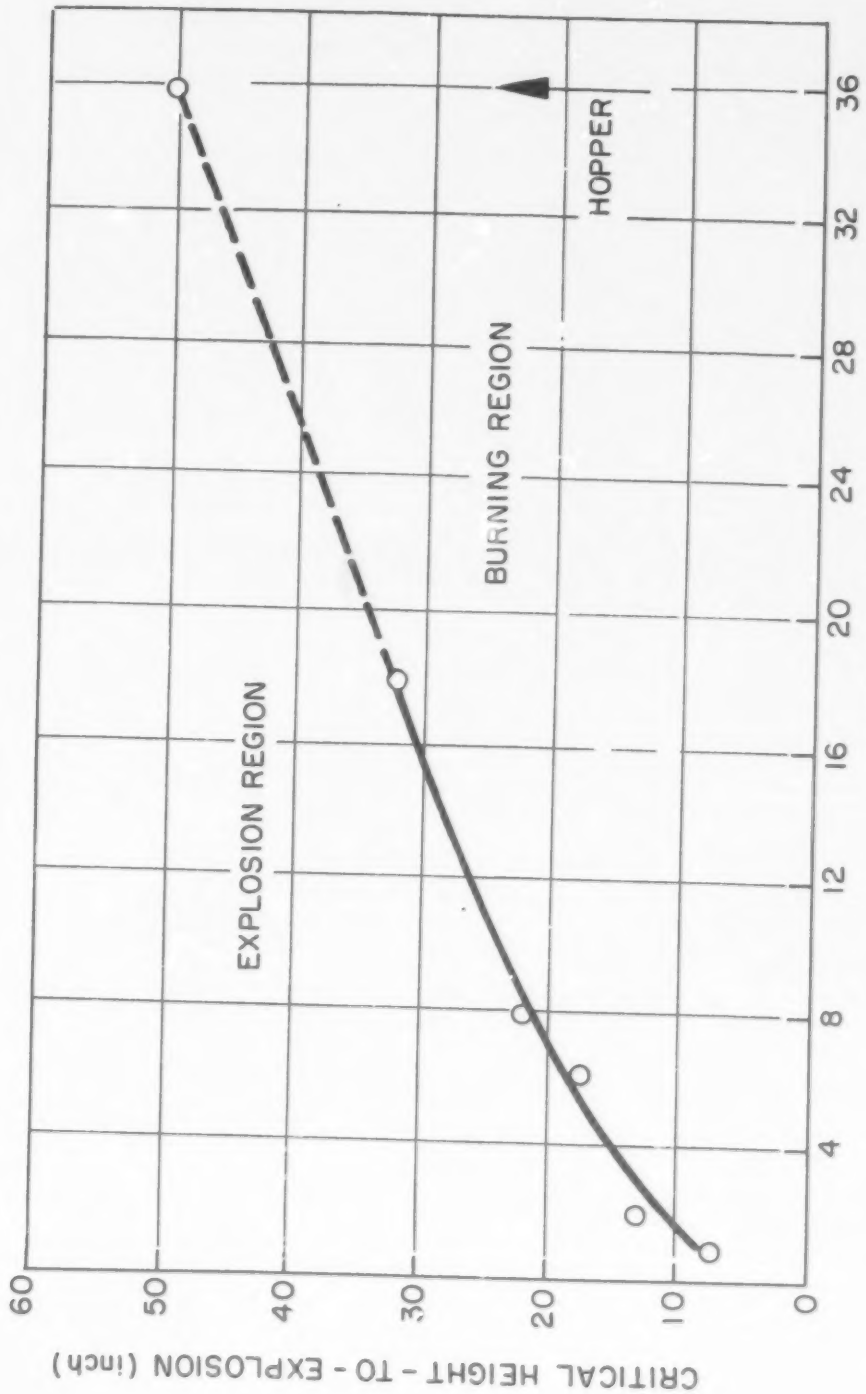


FIGURE 1 : CRITICAL HEIGHT TO EXPLOSION AS A FUNCTION OF DIAMETER FOR MISP PROPELLANT.
(Values Beyond 18in Are By Extrapolation)

PROPELLANT		%NG	A.V. PARTICLE DIAMETER (mm)	(inches)	CONFINEMENT	CRITICAL DETONATION HEIGHT (mm)
Winchester	630	35	.65	.026	steel	160
	231	25	.80	.032	steel	121
	231	25	.80	.032	lexan	210
	630	35	.65	.026	lexan	280
Olin	WC 140	0	.4	.016	steel	368
	TS 3660	12.3	.7	.028	steel	330
	TS 3659	21.6	.4	.016	steel	199
	TS 3661	34.9	.7	.028	steel	298

The Winchester ball powder is roughly spherical The Olin powder is flattened spheres height/diameter 1/4.

TABLE 2: DEFLAGRATION - TO - DETONATION FOR NC/NG POWDERS

on the degree of confinement provided by the container, for example whether of wood or metal, vented or unvented. The classifications based on these criteria are summarized in Table 3 from data of References 3 and 4.

This U.S. system has been adopted by the Netherlands, with modifications to include propellants in the "in-process" stages. Both countries consider that confinement is important, whether provided by the container or the self-confinement provided by the depth of the propellant bed. The U.S., as will be seen from Table 3, emphasizes that venting can reduce the potential for transition to detonation, i.e. change of hazard division from 1.3 to 1.1. Vented Vessel tests are discussed in the next section.

4.0 VENTED VESSEL TESTS

The U.S. has carried out venting tests in both full scale and reduced scale process and storage vessels.

4.1 Full Scale Vented Vessel Tests

These have been carried out by the Hercules Aerospace Division, Radford Army Ammunition Plant for Picatinny Arsenal to establish a hazard classification for M1 SP Propellant for Automated single base finishing operations. The objectives of the work were:

1) Design and test the venting adequacy of a proposed propellant storage hopper for precluding explosive reactions when M1 SP propellant (for 105 mm ammunition) is flame initiated.

2) Establish the hazard classification for 450 pounds of M1 SP propellant in these hoppers for automated single base finishing operations (ASBL) air dry operations.

3) Define the flame initiated explosive characteristics of M1 SP propellant confined in steel.

Objective 3 has been discussed in paragraph 2.1 above.

PROPELLANT	HAZARD DIVISION
Propellant, multiperforated, cannon and rifle, w/web thickness not greater than 0.019 of an inch (.475 mm)	1.3[2]
Propellant, double base and composite grains found to be nonmass-detonating in tests conducted in accordance with TB 700-2	1.3
Propellant, double base and composite grains found to be mass-detonating in tests conducted in accordance with TB 700-2	1.1
Propellant grains, polysulfide-perchlorate, containing not more than 74 percent oxidizer	1.3
Propellant, single base, multi-perforated, w/web thickness greater than 0.019 inch (excluding single base propellant containing 98 percent or more nitrocellulose (NC)	1.3
Propellant, single base, containing 98 percent or more NC	1.1
Propellant, single base, single perforated (rifle)	1.3[2]
Propellant, single base (FNH and NH compositions) single perforated, cannon, w/web thickness not greater than 0.033 of an inch (0.825 mm)	1.3[2]
Propellant, single base, low pressure, for pistols and shotguns, etc.	1.3[2]
Propellant, double base, containing not more than 20 percent nitroglycerin (NG), w/web thickness of 0.0075 of an inch or greater (0.19 mm)	1.3[2]
Propellant, double base (for artillery ammunition) containing over 20 percent NG	1.1
Propellant, double base, w/web thickness less than 0.0075 of an inch, regardless of NG content	1.1

[2]Class 1.3 applies when stored in metal-lined wood boxes; when stored in all-metal containers not designed for quick release of pressure, class 1.1 applies.

TABLE 3: HAZARD CLASSIFICATION OF PROPELLANTS

Objectives 1 and 2 involved studies in vented and unvented drying hoppers of 36 inch square cross section.

In the unvented hoppers, exceeding an 18 inch critical bed depth changed the in-process hazard classification from "burning hazard" to " explosive hazard". The quantity of propellant at 18 inches of bed depth was less than 250 pounds.

The existing hopper, because of baffles, had only a 2.25 sq ft top venting area. The addition of 8 top side vents and 8 bottom side vents, Figure 2 from Ref 1, increased the total vent area to 9.69 sq ft.

Tests established that a propellant surface to hopper vent area of about 660:1 or less is more than adequate for preventing violent explosive reaction for 450 lbs of M1 SP propellant. The height of bed for this weight is about 29 inches. The larger the web (or conversely the smaller the surface area) the less chance of a violent reaction.

In the test with 450 lbs of M1 SP propellant about 150 lbs of unburned propellant were estimated to have been expelled from the hopper and did not contribute to gas generation within the hopper.

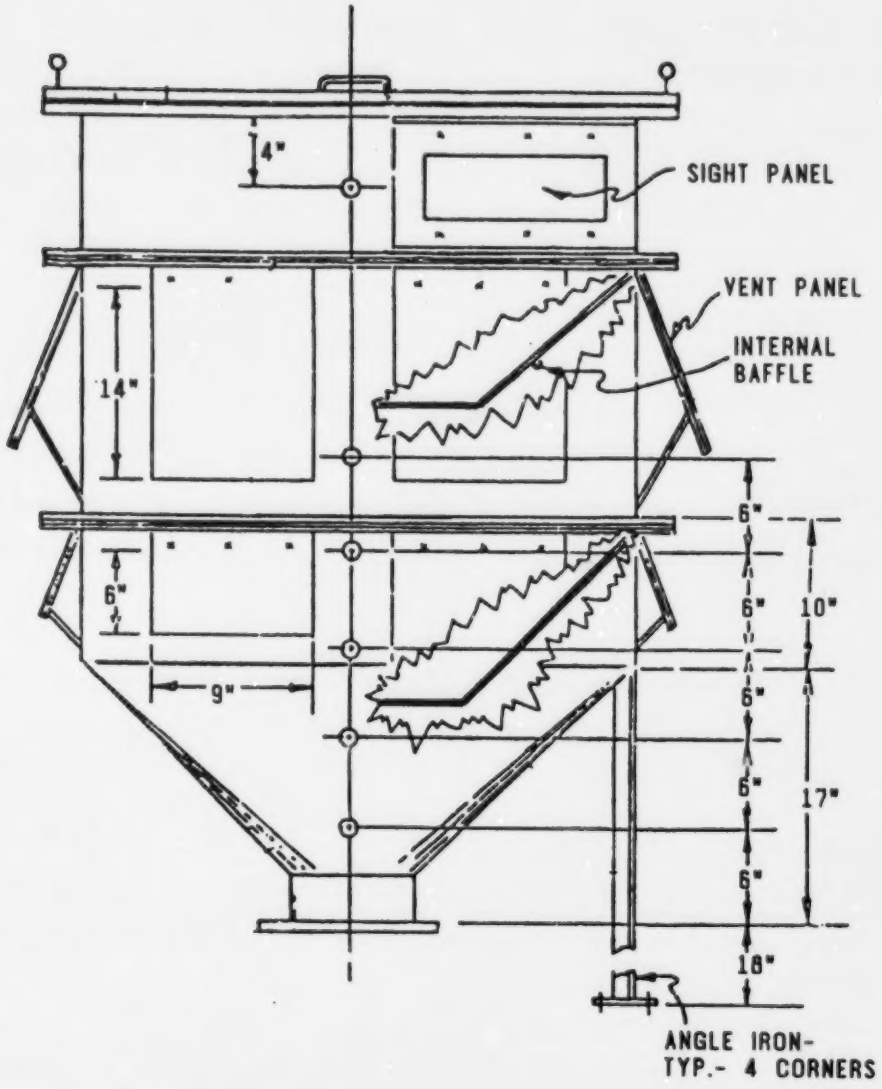
4.2 Reduced Scale Vented Vessel Tests

The full scale hopper tests described in 4.1 above were successful in resolving an immediate problem with a particular propellant in a particular equipment. However there are the disadvantages of: a) cost of test vessels

b) large quantity of propellant required

For this reason the Hercules Company at the Radford Army Ammunition Plant[4] has carried out a program to test lesser quantities of propellant in relatively low cost subscale vessels and to correlate the results to full scale models.

The impetus for the study was the propellant drying operation involving 680 kg of M26 double base propellant in which the nitroglycerin content was greater than 20 percent. This operation would normally require the propellant to be classified as hazard division 1.1, and would require



SIDE VIEW OF HOPPER

FIGURE 2: REVISIONS TO BASIC HOPPER DESIGN.

a much higher facility cost than if the propellant at this stage of manufacture could be classified as H.D. 1.3.

The scale model tests were with three different size vessels, tested at various levels of vent area to determine the effects of vent area and scale size on the pressurization rate for the propellant. The test vessels were scaled to the drier size as 1/4, 1/3, and 1/2 scale and propellant weights were scaled according to the cube of the vessel scaling factor. Results are summarized in Table 4 from Reference 4 and plotted as scaled rate of pressure rise versus scaled vent area in Figure 3

4.3 Mathematical Modeling of Scaled Venting

Figures 3 and 4 and the mathematical modeling discription are taken directly from the paper by Evans, Kristoff and Bolleter . Their work provides a method by which the rate of rise of pressure in any process vessel can be calculated from subscale test results. From this it is then possible to determine whether the vessel has sufficient venting to prevent the transition to explosion or detonation.

The description of the modeling process, after Evans, Kristoff and Bolleter follows:

Math Modeling

The curve shown in Figure 3 is best described by the equation $P = a\overline{A}^{-b.}$ Since $\overline{A}$ is directly related to the vent ratio R, the equation can be rewritten as $P = aR^{b}$. Thus the rate of pressure rise is a function of both propellant surface area, S, and vessel vent area, A_v, since by definition $R = S/A_v$.

The curves in Figure 4 show a decrease in rate of pressure rise as vessel scale increases at a constant vent ratio. This effect can be shown to be caused by the scale factor λ as follows. The subscale vessel produces the same maximum pressure at a given vent ratio as the full-scale vessel, i.e., $P = aR^{m}$, and the pressure rate of rise in a full-scale vessel is $P = P/t$. However,

SCALE	PROP. WT. (kg)	VENT RATIO RANGE	MAX. PRESSURE, RANGE (kPa)	RATE OF PRESSURE RISE RANGE (MPa/s)
1/4	10.6	800-1500	758-2041	43.6-53.6
1/3	25.2	500-1100	146-1717	4.1-47.3
1/2	85.0	267-1100	74-1151	2.9-21.2

TABLE 4: RANGE OF RESULTS OF SUBSCALE TESTS

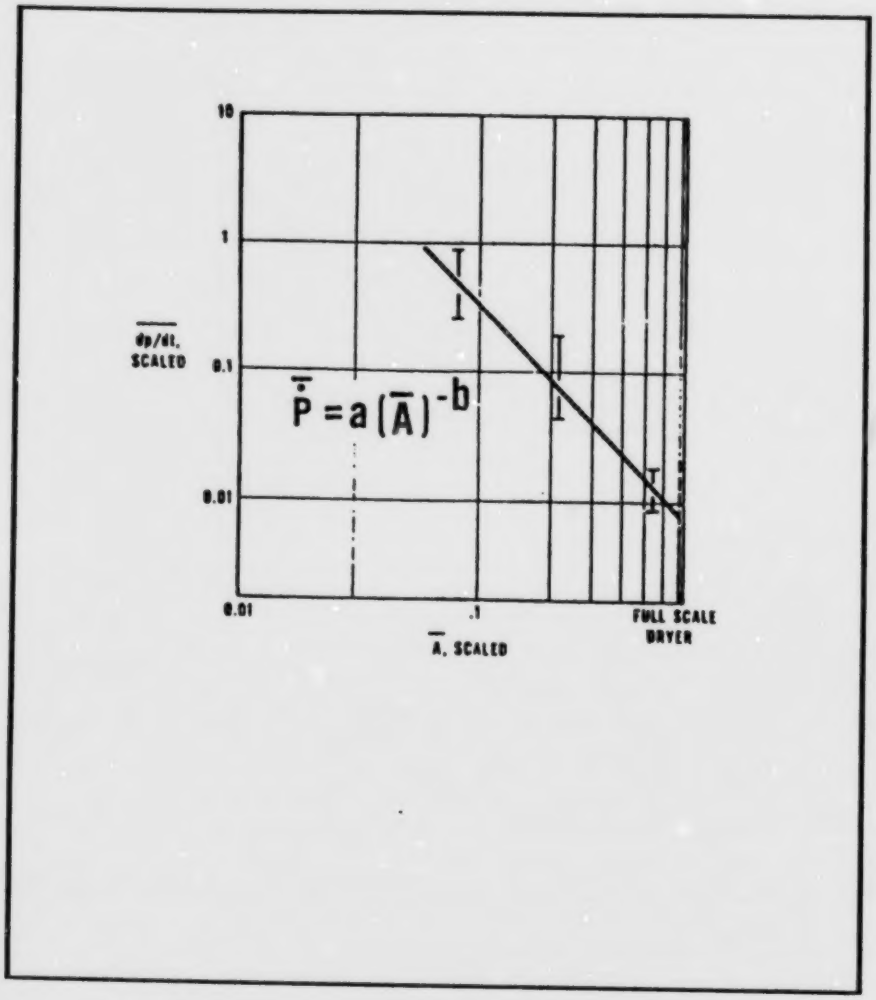


FIGURE 3: SCALED RATE OF PRESSURE RISE VERSUS SCALED VENT AREA.

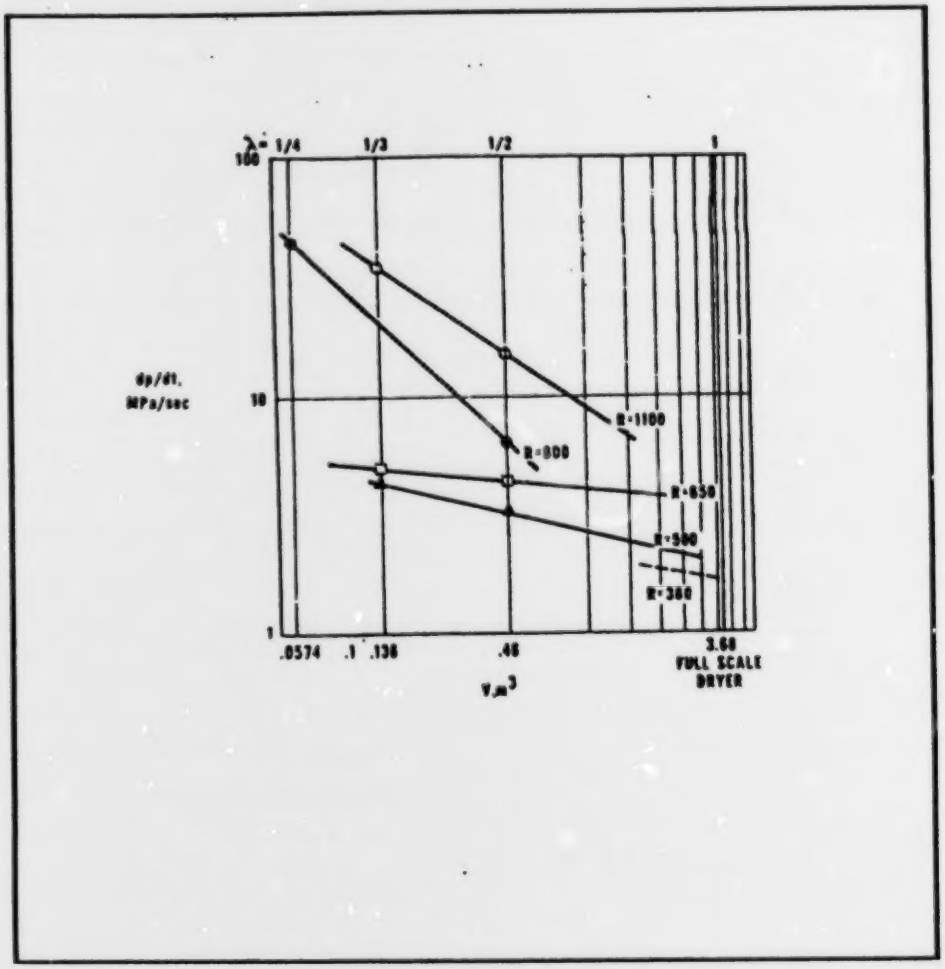


FIGURE 4 : RATE OF PRESSURE RISE VERSUS SCALE AT CONSTANT VENT RATIO.

since a subscale vessel contains less propellant than the full-scale vessel, the burning distance is reduced by Λ. The burning time in the subscale vessel is also reduced by Λ, and the rate of pressure rise becomes

$$\dot{P}_{subscale} = \frac{P}{\Lambda\ t}$$

Thus the pressure rate of rise is seen to increase with a decrease in vessel size.

The relationship in the pressure rate of rise between full and subscale vessels of constant vent ratio is therefore

$$\dot{P}_{fullscale} = \Lambda\ \dot{P}_{subscale}$$

Where vent ratio is not constant, the relationship becomes

$$\dot{P} = \dot{P}_o\, f(R, \Lambda, R\,\Lambda).$$

For propellants of different formulations, differences in values for c and n from the propellant burning rate equation $r = cP^n$ must be considered. To construct a model for all propellants requires the addition of these terms to obtain the form

$$\dot{P} = \dot{P}\, f(R, \Lambda, R\,\Lambda, c, n)$$

Thus the rate of pressure rise in any process vessel can be calculated from subscale test results. By knowing the strength of the process vessel as a function of rate of pressurization, it will be possible to determine whether the vessel will vent, rupture from overpressurization, i.e., explode or transit to a detonation. To preclude a calculated detonation, the vent area of the vessel should be increased. To prevent damage from a calculated overpressurization, more venting could be provided and/or use lower strength materials of construction for all or part of the vessel to allow the vessel to rupture at relatively low pressures.

5.0 REFERENCES

1) C.H. Johnson and R. Rindner "Explosive Tests for Establishing Hazard Classification for M1 SP Propellant in Automated Single-Base Finishing Operations". Picatinny Arsenal Technical Report 5020.

2) Richard R. Bernecker "The Deflagration - to - Detonation Transition Process for High Energy Propellants - A Review." AIAA Journal Vol 24, No 1, Feb 1986.

3) U.S. Department of Defense Contractors Safety Manual for Ammunition and Explosives.

4) J.L. Evans, F.T. Kristoff and W.T. Bolleter "Establishment of Propellant Hazards Classification via Vented Vessel Testing" Hercules Aerospace Division, Radford Army Ammunition Plant, Radford, U.S.A.